Chapter 42
Sweden

Jonas Fridman and Bertil Westerlund

42.1 The Swedish National Forest Inventory

42.1.1 History and Objectives

In Sweden, the National Forest Inventory started in 1923 (Thorell and Östlin 1931). The NFI was established to address concerns on the over-utilisation of wood resources. Nowadays a continuous inventory is performed annually (Fridman et al. 2014). The aim of NFI is to monitor development of forest resources, state of forests, forest health and biodiversity. NFI data and results are used for official reporting nationally, as well as international reporting obligations such as FRA, FOREST EUROPE, the climate convention and the Kyoto protocol, and also for the species and habitat directive (NATURA 2000). Nationwide projections, normally for 100 years, of sustainable cutting levels are estimated using the Heureka RegWise system (Lämås and Eriksson 2003), where NFI data constitute the starting point and provide the necessary tree, site and land-use data for performing the forecasts.

Several research projects have been using data from the Swedish NFI, mainly with focus on biodiversity e.g. Fridman (2000), Fridman and Walheim (2000), Gamfeldt et al. (2013), Vilà et al. (2013). However data is also used for remote sensing applications, e.g. Nilsson et al. (2003) and Reese et al. (2003). There are also examples of methodological papers such as Wulff and Wiersma (2004) and Milberg et al. (2008). A thorough description of the Swedish NFI today, including the development since the first NFI in 1923 can be found in Fridman et al. (2014).

J. Fridman (✉) · B. Westerlund
Division of Forest Resource Data, Department of Forest Resource Management, Umeå, Sweden
e-mail: jonas.fridman@slu.se

B. Westerlund
e-mail: bertil.westerlund@slu.se

C. Vidal et al. (eds.), *National Forest Inventories*,
DOI 10.1007/978-3-319-44015-6_42

The Swedish NFI is organised within the Swedish University of Agricultural Sciences (SLU) and a part of the Swedish Official Statistics system. Statistics derived from NFI data are made freely available to society. The NFI web-site is the primary platform for this, however an annual summary document SKOGSDATA (Forest data) is published and made available online also.

42.1.2 Sampling Methods and Periodicity

Since 1953 the inventory has been conducted annually, covering the whole area of Sweden. In 1983 permanent clusters were established, and since then the NFI is based on both a temporal and a permanent systematic sample stratified into five geographical regions. The distance between clusters, shape of the clusters, number of field plots in a cluster, and distance between plots within a cluster vary between temporal and permanent clusters and regions due to the spatial autocorrelation analysed from earlier NFIs. Permanent clusters are re-inventoried with five-year intervals. Further information on sampling methods used in Sweden's NFI are available in Fridman et al. (2014).

42.1.3 Data Collection

The NFI data consist of two main categories: stand and site description and measured tree data. Stand and site description variables provide information about the forest stand where the field plot is located. If a field plot is divided into several stands, or land-use classes, all stands and land-use classes are described. Trees are assessed on four concentric sample plots, measuring 10, 7, 3.5 and 1 m in radius.

Stand and site data in broad categories consist of:

- Administrative data: geographic position, owner group, restrictions for forestry, etc.
- Land use and land cover: in this case, different classification systems are used to fulfil both national and international reporting needs; previous land use also is assessed, etc.
- Site description: site productivity class, soil type, soil texture, soil moisture, etc.;
- Growing stock: stand structure, species composition, crown cover, development class, age, mean height, damage, previous forest operations, etc.

Tree data consists of:

- Sample tree data: dbh and species
- Sub-sample tree data: height (h), crown height (ch), bark thickness (bt), age, diameter increment (only on temporary sub-sample trees) etc.
- Dead tree data; dbh or diameter at thickest end, species, height/length, and decay class, etc.

Digital versions of all NFI field manuals since 1923 can be downloaded from the NFI web-site.

42.1.4 Data Processing

The estimation consists of the following main steps:

1. Calculation of volume and increment for sub-sample trees
2. Estimation of volume and increment for sample trees
3. Volume expansion factors calculated for each sample tree
4. Area expansion factors calculated for each sample plot/part of sample plot
5. Estimation by stratum-wise summation of area/volume expansion factors.

Sub-sample tree volumes are calculated with general volume functions from (Näslund and Hagberg 1951, 1953). The variables dbh, crown height, bark thickness, and height are used as explanatory variables. Volume is then estimated for each sample tree using secondary form height functions, including plot and tree variance functions to mimic natural variability among trees (Appendix A in Fridman et al. 2014).

Area expansion factors are calculated by dividing the "true" stratum area by the area of sample plots within the stratum. The stratum areas are delivered by the National Land Survey of Sweden. The area estimate for an arbitrary stratum is simply the sum of the area expansion factors from sample plots with characteristics of interest, i.e. forest land. Since the Swedish NFI uses two types of clusters, estimates for each cluster are calculated and weighted with weights that are chosen to minimise the variance of the composite estimator. Total volume estimates are calculated in the same way as area estimates; however, volume expansion factors for each tree are used. Details are presented in appendices A and B to Fridman et al. (2014).

Using a combination of NFI field data and different kinds of remote sensing data, e.g. airborne laser data and/or optical satellite data, wall-to-wall estimates, e.g. of volume per ha, ton biomass per hectare, tree species composition, age and height, are made for productive forestland. Some of these products are free to download from the SLU website (Swedish University of Agricultural Sciences 2016).

42.2 Land Use and Forest Resources

42.2.1 Classification of Land and Forests

42.2.1.1 General Land Classification

Every plot, or part of plot, is assigned to both international classes (FAO definition) and national land use classes (Tables 42.1 and 42.2). The national classes are

Table 42.1 National land area by land-use class according to FAO definition (2008–2012)

Land-use class	Area (1000 ha)	Area (%)
Forest land	28,094	68.9
Other wooded land	2392	5.9
Bare unprod. land	4941	12.1
Other land	5370	1.3
Total land area	40,797	100.0

productive forest, pasture land, arable land, mires, rock surface, sub-alpine woodland, high mountains, urban land, and other land (Table 42.2). Productive forest land is defined as land with potential production capacity of at least 1 $m^3ha^{-1}yr^{-1}$ and not used for other purposes. In Table 42.3 the relationships between the national classes and the FAO Forest Resource Assessment definitions (FAO 2010) can be studied.

Table 42.2 National land area by land use class according to national definition (2008–2012)

Land use class	Area (1000 ha)	Area (%)
Prod. forest land	23,099	56.6
Pasture-land	509	1.2
Arable land	2917	7.2
Mires	5034	12.3
Rock surface	976	2.4
Sub-alpine woodland	973	2.4
Alpine areas	5345	13.1
Urban land	1210	0.3
Other land	733	1.8
Total land area	40,797	100

Table 42.3 National land use/land cover classes and areas, comparison with FAO (2010) definition

Class name	Definition	Area (1000 ha)	Corresponding FRA class
Productive forest land	Productivity ≥1 m^3ha^{-1} $year^{-1}$	23,099	Forest FAWS if protected areas are excluded
Mires, rock surface, sub-alpine woodland	Land use in combination with productivity <1 m^3ha^{-1} $year^{-1}$	6983	Partly forest, partly OWL, partly OL TOF if OL
High mountains	Defined by latitude, longitude and altitude	5345	Partly forest, partly OWL, partly OL TOF if OL
Pasture-, Arable-, other- and Urban land	Defined by land use	5369	OL TOF

42.2.1.2 Forest Classifications by Use

In the Swedish national land use classification system, forest land includes both productive and unproductive forest land (Tables 42.2 and 42.3). In the Swedish Forestry act, commercial forestry is only allowed in productive forest land outside legally protected areas (Table 42.3). Using GIS data of protected areas all NFI estimates with national or international definitions, including both area and volume estimates, can be separated into these categories.

42.2.1.3 Classification by Ownership Categories

Using the National land survey GIS data, all plots are assigned to one of the three ownership categories; Non-industrial private forest owners, Private companies and Others (State, Municipalities, Parishes, etc.). Over half (52 %) of the productive forest land outside reserves is owned by NIPF (non-industrial private forest owners), 23 % by private companies, and 25 % by other ownership categories.

42.2.1.4 Forest Management and Cutting Systems

The majority of forests in Sweden are managed in an even-aged management system with silviculture, pre-commercial thinning, thinning and final felling. A typical Swedish management system could be described as:

- Soil scarification after final felling
- Establishment of new stand with sawing, planting or natural regeneration
- Early pre-commercial thinning
- One to three thinnings
- Final felling after 60–120 years depending on geographical location and main tree species.

Over half (55 %) of removals are from final felling and 30 % from thinning. Increased demand for forest bioenergy, during recent years, includes the harvesting also of branches and tops for biofuel.

42.2.1.5 Legal and Other Restrictions for Wood Use

In the Swedish Forestry act, commercial forestry is only allowed in productive forest land outside legally protected areas. The decision on when to thin is completely up to the forest owner. However, for final felling there are limitations on stand age, i.e. it is not allowed to final fell stands that are too young. Before final felling the forest owners also have to inform the Forest Agency that a final felling will be performed, and also describe how regeneration and considerations for biodiversity will be secured, e.g. leaving retention trees, living or dead. After final felling the Forestry Act also regulates the reforestation operation and specifies criteria that need to be fulfilled.

The major parts of company owned forests in Sweden, and a large part of the privately owned, are certified by Forest Stewardship Council (FSC) and/or Programme for the Endorsement of Forest Certification (PEFC). In these certified areas the forest management of course has to be adapted to the certification criteria.

42.2.1.6 Further Classification of Forests

Further classification of forests in national statistics is usually made by site productivity class, age class, maturity class and forest type. Maturity classes are un-stocked area, thicket stage, thinning stage and final felling stage while forest type is defined by tree species composition.

42.2.2 Wood Resources and Their Use

42.2.2.1 Standing Stock, Increment and Drain

Estimates of growing stock, increment and drain are based on sample tree and sub-sample tree measurements on the sample plots. Using a complex set of functions, primarily published by Näslund and Hagberg (1951, 1953), stem volume is calculated for each sample tree. Stem volume includes all stem parts above the stump i.e. the bole with bark and stem top and includes all trees with dbh ≥ 1 mm measured over bark. The Swedish NFI also produces estimates of the above ground biomass for tree components (stem wood, stem bark, branches and needles) of living trees. Biomass is estimated by applying biomass functions by Marklund (1988) to the sample trees of the Swedish NFI. The biomass is expressed in terms of dry weight. The national definitions of standing stock, increment and drain are detailed in Table 42.4.

Table 42.4 Definitions for standing stock, increment and drain

Quantity	Definition
Standing stock	Volume of trees with dbh ≥ 1.0 mm over bark, including the bole (wood and bark), and stem top, and excluding the above-ground part of the stump
Increment	Volume increment of surviving and ingrown trees with dbh ≥ 1.0 mm. Increment on felled trees included
Drain	Volume of felled trees with dbh ≥ 50 mm over bark and volume of naturally dead trees with dbh ≥ 100 mm

According to Tables 42.5 and 42.6, the growing stock in Sweden continues to increase since the annual increment is larger than the annual felling and the annual natural drain by more than 20 million m^3 annually.

42.2.2.2 Tree Species and Their Commercial Use

The main commercial species are Scots pine (*Pinus sylvestris*, 39 %), spruce (*Picea abies,* 42 %) and birch species (*Betula penduda, Betula pubescens*, 12 %) (Table 42.7). These species are mainly used as sawn timber (pine and spruce) and pulpwood. Recently, the amounts of lodgepole pine (*Pinus contorta*, 1 %) harvested for pulpwood has increased.

The area of productive forest land by dominant tree species is shown in Table 42.7. Here the dominating tree species, using a threshold of ≥65 %, defines the forest type. The threshold is defined by proportion of stems per hectare for

Table 42.5 Growing stock (million m^3) in Sweden distributed on land-use classes (2008–2012)

Land-use class	Scots pine (*Pinus sylvestris*)	Norway spruce (*Picea abies*)	Broadleaves	All
All land	1336	1357	624	3317
TOF	5	3	23	31
OWL	6	2	2	9
Forest of which	1325	1353	599	3277
Prod. Forest of which	1240	1302	563	3106
FAWS	1195	1233	538	2966

Table 42.6 The volume of standing stock, annual increment, and annual drain on productive forest land by tree species (2008–2012)

Tree species	Growing stock (1000 m^3)	Increment (1000 m^3/year)	Drain (1000 m^3/year)
Picea abies (Norway spruce)	1,301,990	50,906	51,445
Pinus sylvestris (Scots Pine)	1,204,393	39,254	27,120
Betula spp. (Birch)	375,170	15,724	8416
Other broadleaves	81,509	3452	1831
Populus tremuloides (Aspen)	51,680	1931	1339
Quercus spp. (Oak)	36,931	916	432
Pinus contorta (Lodgepole pine)	35,593	2970	1290
Fagus sylvatica (European beech)	18,088	499	136
All	3,105,355	115,654	92,009

stands lower than 7 m stand height, and by proportion of basal area in higher stands. This definition is only applicable for productive forest land. Table 42.7 excludes productive forest land within National parks and Nature reserves that are protected from forestry activities.

The distribution of age classes (Table 42.8), i.e. the mean stand age calculated as mean age weighted by basal area on a sample plot with diameter 20 m, shows a dominance of forests in the age classes of 20–60 years. This is mainly an effect of the changes to the management system in the 1950s that are still used today.

42.3 Assessment of Wood Resources

42.3.1 Forest Available for Wood Supply

Every plot, or part of a plot, in the Swedish NFI is assigned to both a national and an international (FAO classes) land-use classification (Table 42.1). Forest available

Table 42.7 Productive forest land by dominant tree species (2008–2012)

Species	Productive area (1000 ha)	Area (%)
Scots pine	8673	38.8
Norway spruce	6025	26.9
Lodgepole pine	477	2.1
Mixed Conifer	3224	14.4
Conifer/Broadleaves	1689	7.5
Other Broadleaves	1335	6
Valuable Broadleaves	212	0.9
Unstocked	744	3.3
Total	22,379	100

Table 42.8 Productive forest land by age classes (2008–2012)

Age–class	Productive area (1000 ha)	Area (%)
0–	911	4.1
3–	1877	8.4
11–	2103	9.4
21–	2434	10.9
31–	2388	10.7
41–	3891	17.4
61–	2334	10.4
81–	1964	8.8
101–	1588	7.1
121–	1321	0.9
141–	1568	3.3
Total	22,379	100

for wood supply (FAWS) is then defined as productive forestland outside protected areas. Whether the Swedish NFI can estimate this area or not depends on the availability of GIS data for protected areas. The Swedish National Environmental Protection Agency provides GIS data of all legally protected areas, and the major forest companies provide additional voluntarily protected areas. However privately owned voluntary protected areas are not mapped, at least not in a way that makes them accessible for the NFI.

The availability for wood supply in Sweden is mainly limited by the following factors:

1. Legally protected areas:
   (a) National parks (forestry not allowed at all)
   (b) Nature reserves and NATURA 2000 areas (forestry not allowed at all, limitations, or no limitations depending on management plans for the reserve)
   (c) Nature conservation areas (forestry not allowed at all, limitations, or no limitations depending on management plans for the area)
   (d) In the Swedish Forestry act, commercial forestry is not allowed on unproductive forest land, i.e. potential site productivity less than 1 m^3/year and hectare.
2. Other protected areas:
   (a) Areas set aside due to certification programs, i.e. FSC, PEFC
   (b) Privately protected areas
   (c) Recreation areas, mainly forest areas close to urban areas.
3. Protective functions:
   Protection of water resources causes limitations to forestry operations near settlements. Protective forests for soil (erosion/avalanches) are mainly occurring in southern Sweden on sand-dunes.
4. Other restrictions
   In the alpine parts of Sweden there are some restriction on forestry, i.e. the forest owners have to apply to the Swedish Forest Agency for permission for final felling and the maximum area is 20 ha. In the reindeer herding areas in north-western Sweden, forest owners also have to communicate with the Sami villages when planning forestry actions. There are also restrictions on forestry for sites with cultural heritage objects, e.g. ancient grave fields, settlements, etc.

Restrictions on forest operations are not directly assessed on the NFI plots, however parameters describing accessibility, such as distance to road, ground surface structure, slope, soil moisture, neighbouring land use classes, and neighbouring forest stands, are registered. These registrations can, together with different kinds of GIS data, e.g. reindeer herding areas, urban areas, water protection areas, etc., can be used for the classification of plots and furthermore estimation of forest areas of different availability of forest supply.

To estimate the area, growing stock, annual growth, etc., for FAWS, the standard estimators of the Swedish NFI are used for plots defined as FAWS.

There are two major problems with using NFI data for estimates of FAWS:

- One specific category of legally protected areas, key habitats, is very small in size, and furthermore, not very common. This leads to low precision in the estimates.
- Mapping of privately owned voluntarily protected areas is not done, or the maps are not accessible to public authorities.

42.3.2 Wood Quality

Wood quality on sample- or sub-sample trees is not assessed in the Swedish NFI. However, a number of indicators for quality are measured on all sub-sample trees, e.g. species, dbh, height, crown length and damages. On pine and spruce we also register diameter of thickest branch (up to two meters height), presence and size of long-bend and/or abrupt bend. On temporary plots tree cores from sub-sample trees can also be analysed for age, ring-width, and rot. All these variables can be used for classification into arbitrary quality classes, including the systems used by the Swedish Timber Classification Association.

No estimates for timber assortments by wood quality are made directly using NFI data. However, in the long-term forecasts using the Heureka RegWise system (Lämås and Eriksson 2003), projections for distributions of assortments are made for timber and pulp wood.

The question of assessment of wood quality in the NFI for living trees has been ongoing since the first Swedish NFI in 1923. A number of different methods have been used, often trying to mirror the quality systems used by the saw mill industry. Thus far no system has been fully successful, mainly due to the simple fact that quality on timber at a saw mill is dominated by indicators not visible on standing trees. During recent years the Swedish NFI has focused on measurable indicators described above, but their usage has so far been limited.

42.3.3 Assessment of Change

42.3.3.1 Assessment and Measurement

The estimation of increment and drain from the Swedish NFI is based on the field measurements on permanent plots at two consecutive points in time combined with field measurements on temporary sample plots. This combination makes it possible to have true measurements of change over a period (normally 5 years) for both increment and drain, as well as detailed measurements of tree cores from temporary sample trees for allocation of growth to specific years within the period.

42.3.3.2 Estimation of Increment

To model the five year volume increment for all sample trees, the following general procedure is used:

1. Volume of permanent and temporary sample trees;
   (i) The volume functions of the Swedish NFI are derived from the sub-sample trees on which diameter, height, crown-length and bark-thickness are measured. For the sub-sample trees published volume functions are used for estimates of single tree volumes. Functions for assigning volumes to all sample trees are derived in-house and includes procedures to mimic the actual variability in the tree population.
2. Permanent sample trees:
   (i) $$\text{Increment} = \text{Volume}_t - \text{Volume}_{t-5}. \qquad (42.1)$$
3. Temporary sample trees, permanent sample trees not measured earlier:
   (i) Tree cores from temporary sub sample trees are measured and volume increment for these trees are calculated using specially developed increment functions;
   (ii) Volume increment on temporary sample trees and permanent sample trees not measured earlier are calculated by secondary increment functions based on the result from I;
   (iii) For every sample tree the increment expansion factor is calculated as the 5 year volume increment ha^{-1} multiplied the probability of inclusion^{-1}.

The national estimate for a 5 year volume increment is performed by summation and weighting of the increment expansion factors for sample trees from both temporary and permanent sample plots, divided by the number of years of data used.

42.3.3.3 Estimation of Fellings

1. Permanent sample trees:
   (i) For all trees felled since the last inventory, the year of felling is assessed and dbh at the time of felling is modelled, i.e. the felled volume of the tree can also be modelled;

(ii) For every felled permanent sample tree the felled volume expansion factor is calculated as the felled volume ha^{-1} multiplied the probability of $inclusion^{-1}$.

2. Stumps on temporary plots and additional stump plots:

    (i) Diameter on stumps felled during the last felling season, i.e. between the start of growing season the calendar year before the inventory and the start of growing season for the calendar year of inventory, is registered. Dbh on the stumps is modelled, i.e. the felled volume of the tree can also be modelled;
    (ii) For every measured stump the felled volume expansion factor is calculated as the felled volume ha^{-1} multiplied the probability of $inclusion^{-1}$.

3. The national estimate for annual felling is performed by summing the felled volume of expansion factors for all sample trees divided by the number of years of data used. Finally the NFI annual estimate for felling is calibrated with the official estimate of annual felling from the Forest Agency.

42.3.3.4 Other Estimation of Changes

Natural losses

1. Permanent and temporary sample trees:

    (i) For all trees that are assessed to have died during last season, dbh is measured, i.e. the volume of the dead tree can be modelled;
    (ii) For all trees that are assessed to have died during last season the volume expansion factor is calculated as the volume ha^{-1} multiplied by the probability of $inclusion^{-1}$.

2. The national estimate for annual losses is performed by summing the volume of expansion factors for all trees that died during last season divided by the number of years of data used.

Change in land use

1. Permanent sample plots

    (i) For all permanent sample plots the point of time of land use change is assessed and registered if a land use change since last inventory is detected. In the system for data capture, information on land cover/land use class at the previous time of inventory is recorded. If the field crew register another class then the system requires that point of time of change is assessed and registered;
    (ii) For all sample plots the area expansion factor is calculated as the plot area multiplied by the probability of $inclusion^{-1}$.

2. The national estimate for changes in land use for the latest 5-year period is performed by summation of the area expansion factors for the change matrix, i.e. land use 5 years before inventory multiplied by the land use for the year of inventory.

All NFI estimators are unbiased and the most effective estimates available will be used. Estimates of change are performed using the permanent sample plots alone. A problem here is that the difference between the two estimates of state, i.e. a change estimate, may not coincide with the "true" change estimate using the permanent sample. In reporting forest state and changes to FRA, estimates using NFI data is used, except felling, since the Swedish Forest Agency (SFA) is responsible for national statistics on felling data. This is obviously also a dilemma with two estimates for felling, of which one is not official. When needed the NFI estimates are calibrated using the SFA estimates and distributions, e.g. felling separated on tree species, land use classes, diameter etc., can be used directly.

42.3.4 Other Wooded Land and Trees Outside Forests

The Swedish NFI covers all land use classes meaning that the same measurement methods are used for all land use classes. The only land-use classes excluded totally from tree measurements are Alpine areas and Urban land. Originally, the reasons for not measuring trees in Alpine areas were due to restricted accessibility, and thus high costs. However, from 2003 the assessment of Alpine areas is the responsibility of another Swedish monitoring programme (National Inventory of Landscapes in Sweden), although no estimates on volume or biomass have been carried out yet. The reason for excluding Urban land is due to concerns on entering private gardens, etc.

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