

Chapter 22

Lithuania

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22.1 Development of the Lithuanian National Forest Inventory

The first stand level forest inventories on Lithuanian territory were started in 1801 (Table 22.1). Before 1912, some parts of Lithuania's forests had been inventoried up to five times, but the inventories were not conducted on a regular schedule and the whole country was not inventoried. Usually just the largest forest areas were inventoried (Brukas et al. 2002).

Regularly scheduled, stand level forest inventories of the whole country started in 1922. The forests of Lithuania were inventoried over a period of 10–20 years. Usually every year one tenth of the country's territory was inventoried. Forest mapping, using geographical information system (GIS) techniques, was started in 1995, and the sixth stand level inventory of Lithuania was started in 2002. The stand level forest inventories are the basis for forest management planning and regular forest resources assessment. According to Lithuanian Forest Law (1994), stand level forest inventories and mapping should be executed regularly every 10 years throughout the country independent of forest ownership.

Databases including descriptions and digital borders for all stands have been organized on the SQL server DB database (DB) management system since 1997 (Brukas et al. 2002). Since 2003 these data have formed the basis for Lithuania's state cadastre and are managed by the State Forest Survey Service.

A pilot inventory based on sampling methods was conducted in Lithuanian state forests in 1967–1969. Investigation of continuous forest inventory methods using permanent plots was started in 1976 in Dubrava forests (5,000 ha, 188 sample plots) (Kuliešis 1999b). Using the results of five repeated measurements obtained at 5-year intervals new methods for allocating plots, marking, data processing and analysis were developed. The results formed the basis for the theoretical and

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Table 22.1 Forest inventories in Lithuania

Inventory type	Years	Method	Remarks
Stand level	1801–1912	Ocular assessment – measurements	Irregular schedule, forest land level
Stand level I	1922–1956	Ocular assessment – measurements	Regular schedule, country level
Stand level II	1958–1963	Ocular assessment – measurements Use of aerial photographs for mapping	Regular schedule, country level
Stand level III	1966–1977	Ocular assessment – measurements Non-wood resources, forest soil and site inventory started	Regular schedule, country level
NFI, sampling	1967–1969	Measurements 5,000 sample plots, six plots per cluster	State forests, temporary plots 50–800 m ²
Stand level IV	1978–1987	Ocular assessment – measurements Prognosis of forest stand characteristics	Regular schedule, country level
Stand level V	1988–2001	Ocular assessment – measurements Geographical information system (GIS) technologies implemented	Regular schedule, country level
Stand level VI	2002– (in progress)	Ocular assessment – measurements Sampling of mature stands implemented	Regular schedule, country level
NFI I, sampling	1998–2002	Sampling using Geographic Information System (GIS)	5,600 permanent plots established
NFI II, sampling	2003–2007	Sampling using GIS, Temporary plots implemented	Remeasurement of permanent plots (~1,120 annually), establishment of new permanent and temporary plots
NFI III, sampling	2008–2012 (in progress)	Integration of National Forest Inventory (NFI) and Forest health monitoring (FHM). Inventory of decomposition level of dead wood	

methodological aspects of the sample-based NFI. In 1996, experimental NFI investigations in the forests of the Jūrė district (3,000 ha, 169 sample plots) helped to finalize preparation of a continuous sampling inventory in Lithuanian forests by improving the design, technical aspects of measurements, estimation methods, and data processing and analysis (Kuliešis 1996; Kasperavičius 1997). GIS techniques were adopted for allocating sample plots. On March 17, 1998, the vice-minister of the Agriculture and Forestry Ministry signed an order to begin a sample-based Lithuanian NFI (Ministry of Agriculture and Forestry 1998). The allocation and measurement of permanent plots was finished in 2002 (Kuliešis et al. 2003) and remeasurement of these plots and establishment of new temporary plots was started in 2003 (Kuliešis et al. 2009).

The aim of the sample-based National Forest Inventory (NFI) is to conduct a thorough monitoring of Lithuanian forests for efficient assessment of the main forest variables in the country or its regions. High priority was especially given to estimation of volume increment and its structure. In accordance with Lithuanian Forest Law, the focus of the NFI is the land portion of the country used for growing forests. Continuous management of the land area of the entire country is ensured by observing land property dynamics and evaluating forest land using data from permanent and temporary NFI plots.

The main tasks of the NFI in all Lithuanian forests according to ownership category are:

1. To manage the dynamics of forest areas
2. To estimate wood resources, increment, their structure and the dynamics with pre-defined accuracies
3. To determine the validity of other methods for inventoring wood resources
4. To guarantee the flow of information about:
 - (a) Growing stock resources and their consumption
 - (b) Gross increment and its consumption
 - (c) Management efficiency at the state level
 - (d) Control of forest felling, reforestation and carbon balance
 - (e) Reliable strategic planning of forest development
5. To assess the state of forest sites, their yield dynamics and usage efficiency
6. To assess the current state of forests
7. To assess the dynamics of forest ecosystems, their health, damages and biodiversity

22.2 The Use and Users of the Results

The Lithuanian NFI provides government institutions with information of known accuracy for strategic large-area forest management planning and estimates of forestry efficiency. The NFI is the source of accurate forest information used for forest industry and its investments, environmental decisions and policy making, biodiversity estimation and carbon stock assessment. The Lithuanian NFI also provides statistical information about country forest resources for national and international reporting to bodies such as the Food and Agricultural Organization of the United Nations (FAO) and its Forest Resources Assessment, and the Ministerial Conference on the Protection of Forests in Europe (MCPFE). Further, NFI data is anticipated to serve as a basis for modeling forest growth under a variety of silvicultural scenarios. NFI data users include scientists in a wide range of disciplines such as forest management, silviculture, forest productivity, forest soils, and biology.

Table 22.2 The main NFI quantities and definitions compared with FAO definitions

E43 reference definition	National definition
Forest is land with tree crown cover (or equivalent stocking level) of more than 10% and area of more than 0.5 ha including wind breaks and shelter-belts of trees with area of more than 0.5 ha and width of more than 20 m	Stocking level – more than 30% Area – more than 0.1 ha Width of shelter-belts – more than 10 m
Growing stock is the volume of living and standing stems over a specified land area. Includes: stem volume above stump measured over bark to top (0 cm), all trees with <i>dbh</i> over 0 cm	Growing stock is the volume of living stems with bark Stem is defined from root collar up to terminal bud of stem
Gross annual increment is average annual volume of increment over the reference period of all trees measured to a minimum diameter at breast height (<i>dbh</i>) of 0 cm	Increment is the change of total stem volume including bark, increment of dead and felled trees and ingrowth during two successive inventories

22.3 Current Estimates

National definitions are given a legal basis within Lithuanian forest law (Parliament of Lithuanian Republic 1994) with more detailed definitions provided in the Statute of Lithuanian state forest cadastre (Government of Lithuanian Republic 2003), the Manual of National Forest Inventory (Kuliešis et al. 2005), and the instruction for stand level forest inventories (State Forest Survey Service 2007). The main differences between national definitions and COST Action E43 definitions, that are near UNECE/FAO TBFRA 2000 definitions (UNECE/FAO 1997, UNECE and FAO 2000), of forest, forest land, growing stock volume, annual increment are presented in the Table 22.2.

In Lithuania's Forest law, forest is defined as land not less than 0.1 ha, covered by trees or other forest vegetation or temporarily unstocked (cleared or burned areas). The definition of forest includes shelterbelts of trees with widths of more than 10 m. Forest stands with stocking levels (approximately equivalent to crown cover) less than 30% are not acceptable for high productivity forestry. Forest stands whose trees cannot reach or exceed the 30% stocking level should be removed and reestablished. All forest land, independently of current cover level, are under forest law protection, which means obligatory reforestation of such areas. According to national regulation, afforestation of abandoned agricultural lands is ascertained in case forest crown cover attains 30% of an area not less than 0.1 ha. The total area of Lithuanian forest land of less than 0.5 ha is approximately 7,300 ha and can always be estimated using forest cadastre data (Table 22.3). Characteristics and deviations of the main variables are presented using estimates from the 2003–2007 NFI in Table 22.3 3 (Kuliešis et al. 2009).

In the Lithuanian NFI, measurement of the main tree variables is based on the location of the root collar, which is the ground surface position when tree was planted or when it germinated, and the total length of the stem from root collar to the terminal bud of the stem. Inclusion or exclusion of various tree parts such as

Table 22.3 Basic area and volume estimates of Lithuania (NFI 2003–2007)

Quantity	Estimate	Deviation from FAO definition (%)	SE ^a (%)
Forest land area (1,000 ha)	2,108.1	+0.4	1.0
Forest land area covered by trees (1,000 ha)	2,036.2	+0.4	1.0
Other wooded land area (1,000 ha)	77.0 ^b	–	n.a. ^c
Forest roads, technological lines (1,000 ha)	29.9	0	10.0
Growing stock volume on forest land (million cubic metre)	466.7	+1.7	1.3
Annual increment of growing stock volume on forest land (million cubic metre per year)	15.9	+1.7	1.2
Annual changes of growing stock volume (million cubic metre per year)	+2.9	0	17.2
Annually dead trees, million cubic metre (included stems with <i>dbh</i> > 2.0 cm)	3.3	0	2.7
Total land and inland water area (1,000 ha)	6,530.0	–	– ^d

^aStandard error.

^bLand Fund of the Republic of Lithuania (2007).

^cNot available.

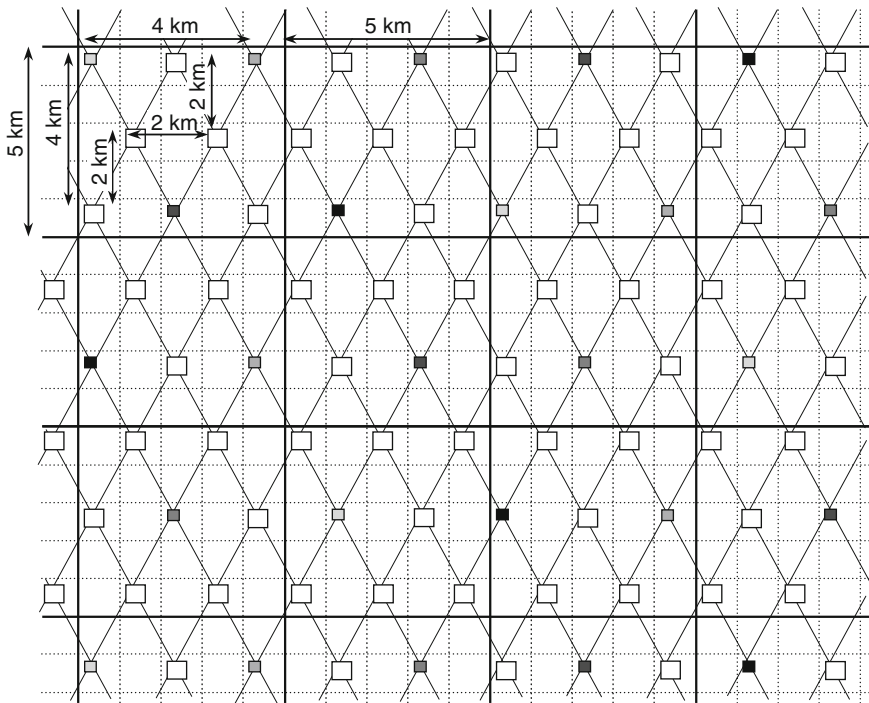
^dAssumed to be error free.

stump, top of stem and size of branches is the main reason for growing stock volume definition changes during the last 7 years of global forest resources assessments. For the Lithuanian NFI, a stem without all of its parts (stump, stem top) or with only some parts (branches) is not a natural body and cannot be the basis for forest resources assessments. In addition, exclusion of the stump leads to difficulties because stump size depends on cutting techniques. Thus, unlike reference definitions, the Lithuanian NFI definition of growing stock includes aboveground stumps.

On the other hand, stump volume accounts for only 1.5–2.0% of growing stock volume for Lithuania and is within the accuracy limits for estimates of growing stock volume. In the Lithuanian NFI, all planted and naturally regenerated trees with *dbh* of at least 2.1 cm are measured. An analysis of the structure of growing stock volume showed that trees with *dbh* between 2.1 and 4.0 cm account for only 0.2% of growing stock volume. Thus, the volume of trees with *dbh* < 2.1 cm is negligible. Similarly, the proportion of gross annual increment in trees with *dbh* < 2 cm is also negligible. Gross annual increment estimated from permanent plots is differentiated into three main parts: volume of deadwood, volume of felled trees by final or intermediate fellings which includes drain, and volume increase due to growth. The mean annual change in growing stock volume is estimated by using differences in tree volumes for two successive inventories, as seen in Table 22.3.

22.4 Sampling Design

The NFI is based on continuous, multistage sampling and GIS technology and is organized in the same manner for all Lithuanian forests. Sampling is conducted using a 4 × 4-km systematic grid with a random starting point (Fig. 22.1).



- † Grid of orthophotographic maps (5 × 5 km), tract (250 × 250 m in size) with 4 permanent sample plots, tract measurement year:
 - = 1998, 2003, 2008, ... , ■ = 2001, 2006, 2011, ... ,
 - ▒ = 1999, 2004, 2009, ... , ■ = 2002, 2007, 2012,
 - = 2000, 2005, 2010, ... ,
- Tract (500 × 500 m in size) with 4 temporary and 4 stump inventory sample plots

Fig. 22.1 Distribution of permanent and temporary clusters

The systematic grid assures a uniform distribution of plots over the entire country and regular management of conversion amongst land use categories. The sample plots are arranged into clusters (Fig. 22.2) and include permanent, regularly measured and temporary plots. Permanent plots are marked in a way which guarantees their visibility only for inventory teams and invisibility for all other persons. Taking into account the number of homogeneous stands (strata), minimal growing stock volume and increment estimation accuracy, 5,600 permanent sample plots were established on forest land over a 5-year period. Approximately 1,120 permanent sample plots are remeasured each year. The NFI plots cover the entire country each year with the total number of plots measured over the 5-year inventory cycle reaching a sampling intensity of one sample plot per 400 ha. The inventory

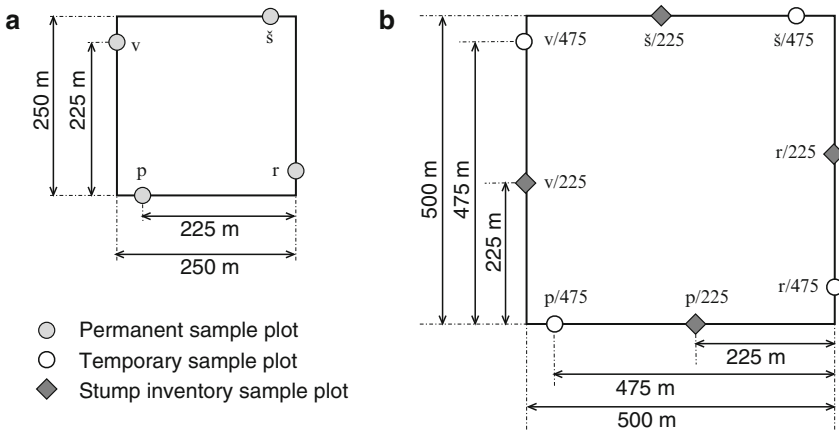


Fig. 22.2 Location of sample plots in clusters: a) permanent, b) temporary, and stump plots

cycle is 5 years. Additional temporary plots are established every year during the following 5-year period. The number of temporary plots in each 5-year period is one-third the number of permanent plots and averages 380 plots per year.

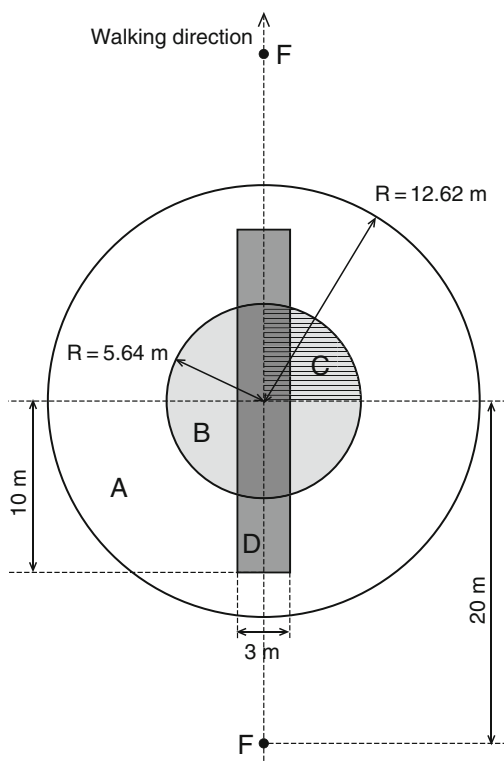
22.4.1 Sample Plots

The principal sample unit is a permanent or temporary plot of 12.62 m radius and area of 500 m² (Fig. 22.3). The radius of plots on sloping terrain is increased to accommodate the sloping surface. On the main 500 m² plot, all trees with *dbh* > 14.0 cm are measured (Fig. 22.3). In the center of the plot, another 100 m² circular plot is used to measure all trees with *dbh* > 6.0 cm. In the first quarter of the 100 m² plot, i.e. on 25 m² area, naturally growing saplings, shoots over 2.0 cm in diameter at 1.3 m height as well as all planted trees, regardless of their dimensions, are measured and mapped. Undergrowth and underbrush are recorded in a 3 × 20-m strip plot allocated within the main plot. At a distance of 20 m from the plot center, two angle count plots with basal area factor *K* = 2 are established. The data from this inventory are used to determine stand species composition, age and increment according to primary measurement data.

Permanent plot clusters are square with 250-m long edges orientated in the north–south and east–west directions and include four sample plots. Temporary plot clusters are square with 500-m long edges and also include four sample plots (Fig. 22.2). In the centre of each side of each cluster, a stump plot is also established.

Analyses are based on combining data from repeated measurements of permanent plots and measurements of temporary plots and data from assessment using satellite image maps and aerial photos (Kuliešis 1999a).

Fig. 22.3 Construction of the main sample plot: A, B – circular plots, C quarter of a circular plot, respectively 500, 100, and 25 m² in size, D – 60 m² strip and F – angle count plots



22.4.2 Management, Personnel, Measurement Techniques, Quality Assurance

The State Forest Survey Service is responsible for conducting timely inventories using current technology as described in fieldwork instructions and in statistical publications that report results. Forest measurements are done by three fieldwork crews, two in different regions (Fig. 22.4) for permanent plots and one for temporary plots. Each year one-fifth of all permanent plots in the country are assessed. The time between successive plot measurements should not exceed 5 years ± 20 days. A group of five to six specialists plan the inventories; manage, process, and analyze the data; develop programs and prepare statistical reports.

Field teams use global positioning system (GPS) Pro XRS receivers, measurement tapes and compasses for plot location and re-location. Ultra sound distance measures “Forestor” are used for circular plots, and angle count devices with basal area factor $K = 2$ are used for angle count plot. Digital calipers “Mantax Digitech” automatically transmit data to Tablet PC “GoBook” (Itronix) field data recorders. Field computers, using logical checks do primary data quality control. For height measurement field teams use “Haglölf” instruments.

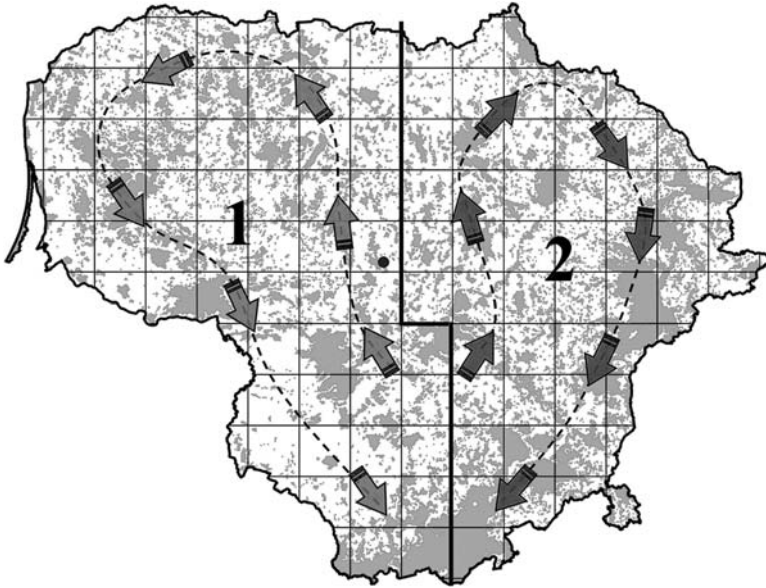


Fig. 22.4 Scheme of Lithuanian NFI inventory regions and the sequence of field measurements

Data are delivered to the State Forest Survey Service every week, where quality control data checks are performed using PC and manual procedures. The final quality check is done after the field season but before the data processing. Members of the quality control group regularly check measurements for permanent and temporary sample plots. Not less than 5% of all sample plots are checked. Quality control results are used to estimate the quality of work done and the competence of employees, to improve the methodology of measurement, and to correct major mistakes. Data quality control for the Lithuanian NFI includes assessment data reliability, accuracy and objectivity. The data quality control system includes:

- Documentation of field and data processing methods, models and algorithms (Kuliešis et al. 2003)
- Statute of Lithuanian NFI, approved in 2004 by Ministry of Environment (2004)
- Field manuals (Lithuanian) for the years 1998, 1999, 2000, 2004
- Grid of temporary plots (one third from permanent) for regular, annual measurement
- Training and control of field teams
- Statistical checks (logic, relationship between various inventory data) of every measurement
- Audit of the NFI by the Ministry of Environment.

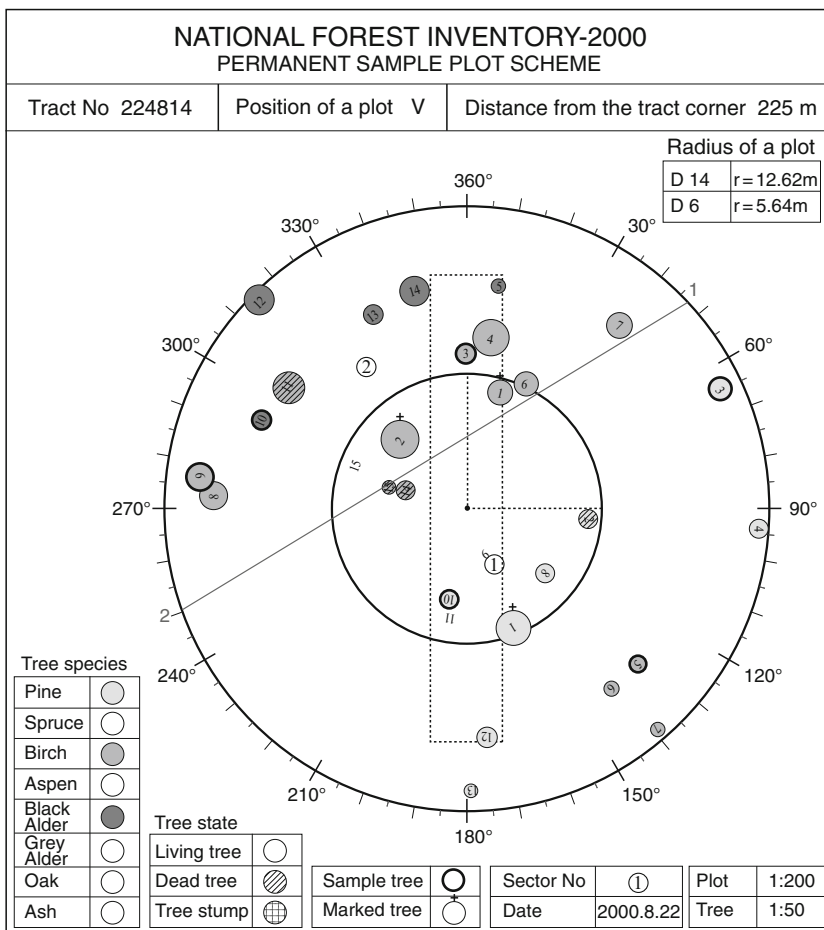


Fig. 22.5 Plan of tree location in a permanent plot

22.4.3 Field Operations

An ordinary work routine is carried out for detection of centers of sample plots and their location. Orthophoto maps, forest maps and GPS receivers are used to identify plot centers. Within a sample plot the usual measurements are carried out: mapping of trees (Fig. 22.5), callipering of trees and stumps, measurement of sample trees height and crown length, tree increment, defoliation and damages, description of soil, site and stand, inventory of understorey, regeneration and underbrush, inventory of cuttings for the previous 5 years, plantations up to 10 years, and assessment of a wide-range of other parameters. Sample plots occurring on the boundaries of several forest compartments or different land use categories are divided into smaller

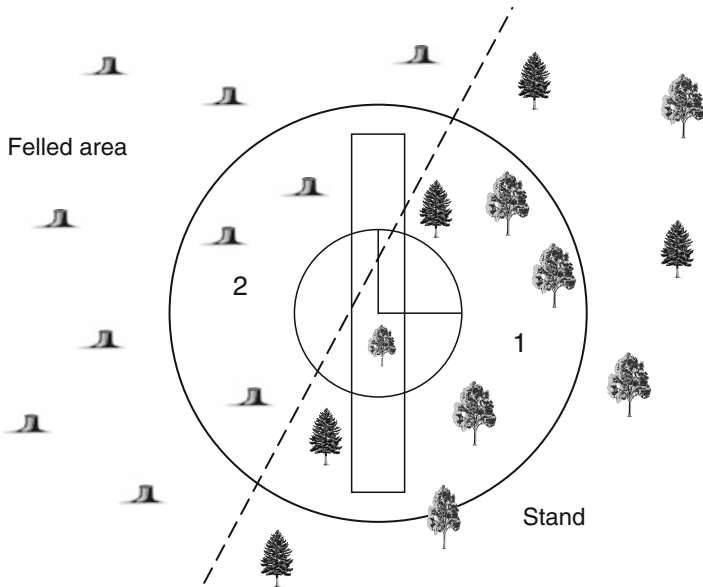


Fig. 22.6 Diagram of plot division into sectors (cutting area, stand)

units, i.e. sectors (Fig. 22.6). Each sector is described separately, with trees being measured in a separate sampling unit.

Using data from measured sample plots, the most important quantities are estimated: volume of growing stock and its increment, mortality and allowable cut. The observation cycle of a permanent plot ceases when the stand containing the plot is felled. In the same place a new observation cycle of forest regeneration and its further growth is started.

22.4.4 Production of Forest Statistics

The NFI supplies the data necessary for preparation of various forest statistical reports and for forest management. Estimation of current forest statistics is based on a combination of data obtained for the 5-year inventory period from remeasured permanent plots, temporary plots measured for the first time, and stump plots (Fig. 22.7). Evaluations of change on permanent plots permits efficient forest management, estimation of biodiversity changes, and estimation of land use changes (Fig. 22.7). Estimates of a large number of quantities required for various NFI users are based on a combination of plant measurements from plots and aerial plot assessments (Table 22.4).

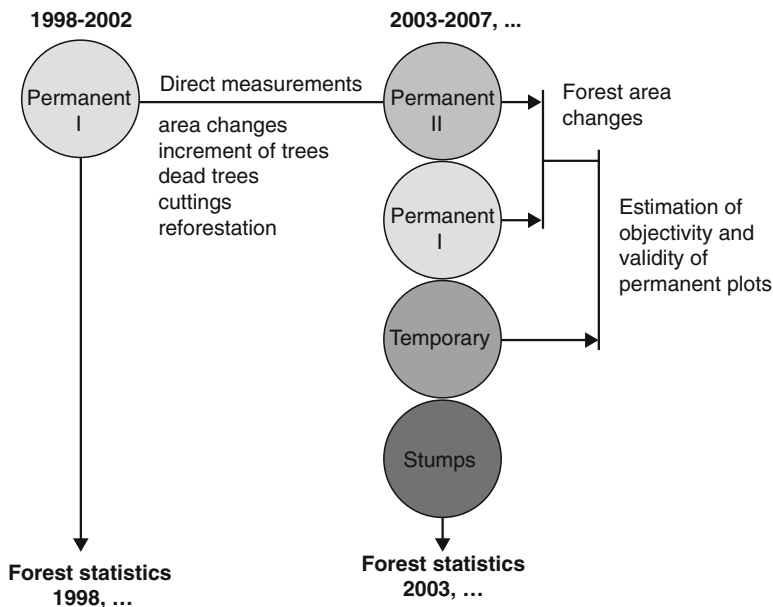


Fig. 22.7 Estimation of forest statistics and its changes using NFI sample plots

Table 22.4 NFI data structure

NFI data structure		
Dimensions of plants	State of plants	Aerial characteristics
Trees	Species	Ownership
Diameter 1,3 m	Storey	Land use category
0,0 m	Growing	Protective status (forest group, subgroup)
Height	Dead	Administrative regions
Length of crown	Cut	Site type
Age	Quality class	Forest type
Volume $V=f(D,H,F_{DH})$	Damages	Age class
Increment $Z_V=f(V_A, V_{A-n})$	- type	Site index H_{AB}
Understorey	- cause	D_{AB}
Height	- position	Stocking level
Age	- intensity	Species composition
Underbrush	Defoliation	
Height		

Estimates and their accuracy for the following variables are calculated for all Lithuanian forests by ownership categories, counties, site types and other administrative divisions:

- Area of a specified land class
- Area distribution by land category, tree species, age, stocking level, site type

- Tree species composition by area and growing stock volume
- Growing stock volume classified by tree species and diameter
- Current increment classified by tree species and diameter
- Area of cuttings and its distribution by kinds of cuttings
- Volume of removed trees classified by tree species and diameter
- Volume of dead, windthrown and windbroken trees classified by tree species and diameter
- Growing stock volume increment balance and its classified by tree species and diameter
- Extent of tree damages, their causes and intensity
- Abundance of understorey and natural regeneration, their structure and damages
- Abundance of underbrush and damages
- Resources of mature stands and potential final forest use
- Characteristics of Lithuanian forests by counties

Sampling conducted by the NFI is considered objective in the sense that instrumental methods are assumed to be reliable and of known precision. Thus, the data collected over the course of NFI form the basis for objective Lithuanian forest estimates which can be used to assess the validity of data obtained by other methods.

22.4.5 The General Characteristics of NFI Not Previously Noted

- Number of permanent plots: 5,737 for the previous 5-year cycle with approximately 1,150 measured annually, temporary plots – approximately 380 measured annually (Kuliešis et al. 2009)
- Permanent plots – with mapping of trees (tree position is recorded with distance from plot center to tree center and azimuth)
- Temporary plots – without mapping of trees
- Delineation of circular plots into sector by forest type, age, forest site, ownership, administrative unit
- Two angle count plots per each circular plot for estimation of age and increment of trees during establishment of permanent plots
- Number of trees per circular plot: approximately 30
- Number of trees per angle count plot: approximately 15
- Number of sample trees approximately 7–12 in every plot
- Forest regeneration: on strip plots 3 m × 20 m size species, state of plants, height, number, damages
- Dead trees – standing and lying on every circle plot
- Forest type: development stage, vertical structure, species composition, stocking level, silvicultural treatment
- Forest site type and soil: indicators of forest site type, main characteristics of soil up to 1.2 m deep

- Protective functions of stand
- Damages of trees: type, source, position, intensity

22.5 Estimation Techniques

22.5.1 Area Estimation

Estimation of the total forest land area using data from annual plot measurements for a certain number of years.

$$Q_m = Q \cdot p_m, \quad (22.1)$$

or

$$Q_m = K_m \cdot q_R, \quad (22.2)$$

$$Q_m = \frac{q_m \cdot q_R}{500}; \quad (22.3)$$

where: Q – total area of Lithuanian territory, 6,530,000 ha

Q_m – forest land area, ha

p_m – part of forest land area

q_R – area, represented by one plot according to I year measurement data is equal to 2,000 ha, II – 1,000 ha, III – $666^{2/3}$ ha, IV – 500 ha, V – 400 ha. During remeasurements, together with temporary plots VI – 375 ha, VII – $352^{16/17}$ ha, VIII – $333^{1/3}$ ha, IX – $315^{15/19}$ ha, X – 300 ha

q_m – area of all plots and sectors on forest land, m²

$$p_m = \frac{K_m}{K}; \quad (22.4)$$

K_m – sum of plots or their parts on forest land, estimated during inventory

K – total number of plots in Lithuania

$$K = \frac{Q}{q_R}; \quad (22.5)$$

The error P_{Q_m} of forest land assessment, in percent

$$P_{Q_m} = \sqrt{\frac{1 - p_m}{(K - 1)p_m}} \cdot 100; \quad (22.6)$$

where: p_m , and K are as in formula (22.4)

22.5.2 Growing Stock Volume Estimation

Detailed algorithms for the estimation of all stand characteristics in a sample plot are given in a series of publications by Kuliešis (1985, 1989, 1993). Only techniques and algorithms for the most important parameters related to growing stock volume and increment are provided here. Estimation of growing stock volume and increment during remeasurements is based on tree-level observations and measurements.

For each tree in a sample plot, tree species, storey, and condition are observed and diameters at 1.3 m height are measured. For sample trees, which average 3–5 trees of dominant species and not less than 1–2 trees of other species, storeys, heights and butt diameters are measured. Using sample tree measurement data and regression or standard models of tree height based on diameter, the heights of all trees are estimated. Generally, tree heights and the corresponding storey and species are measured for at least five trees per plot, and the heights of remaining trees are estimated using the model,

$$h_{ij} = \bar{H}_i \cdot R_{ij}; \quad (22.7)$$

where: \bar{H}_i – mean height of trees of i species on the analysed storey of a sample plot.

$$\bar{H}_i = \frac{\bar{H}_{ai}}{R_{ij}}; \quad (22.8)$$

\bar{H}_{ai} – mean height of sample trees of i species

R_{ij} – reductional height value obtained from the dependence model of relative tree height on relative diameter

$$\bar{H}_{ai} = \frac{\sum_{j=1}^{k_{ai}} h_{aij} \cdot d_{aij}^2}{\sum_{j=1}^{k_{ai}} d_{aij}^2}; \quad (22.9)$$

h_{aij} , d_{aij} – height (m) and diameter (cm) of sample trees, respectively

k_{ai} – number of sample trees of i species in a plot (Kuliešis 1993)

$$R_{ij} = f(d_{ij}, \bar{D}_i); \quad (22.10)$$

d_{ij} – diameter of j tree at 1.3 m height, cm for i tree species

\bar{D}_i – mean diameter of i species trees in a plot

$$\bar{D}_i = \sqrt{\frac{\sum_{j=1}^{k_i} d_{ij}^2}{k_i}}; \quad (22.11)$$

k_i – number of i species trees in a plot

Tree volume from the root collar to the stem top in a plot is estimated as,

$$V_{ij} = \frac{\pi d_{ij}^2}{4 \cdot 10,000} \cdot h_{ij} \cdot F_{h_{ij}d_{ij}}; \quad (22.12)$$

where: d_{ij} – measured diameter of j tree of i species at 1.3 m height, cm

h_{ij} – height of the same tree estimated by (22.7) formula, m

$F_{h_{ij}d_{ij}}$ – form factor of a tree, derived from its dependence on tree height and diameter (Kuliešis 1993).

The growing stock volume of stand storey, tree species or trees of a corresponding state is ascertained by summarizing the volume of trees having corresponding features.

22.5.3 Increment Estimation

Periodic increment is defined for each tree as the difference between tree volumes for successive measurements:

$$Z_{vij} = V_{Aij} - V_{A-nij}; \quad (22.13)$$

where: Z_{vij} – volume increment of j tree of i species per n years

V_{Aij} – volume of j tree of i species during measurement

V_{A-nij} – volume of j tree of i species n years ago

With repeated measurements on permanent sample plots, annual stem volume increment is estimated directly using (22.13) formula. Periodic increment of felled or dead trees in the period between inventories is estimated as half the increment of trees of similar diameter and height for the same period.

For the first measurement of permanent plots or measurements of temporary plots, tree volume n years ago, V_{A-nij} , was estimated as,

$$V_{A-nij} = \frac{\pi \cdot d_{A-nij}^2}{4 \cdot 10,000} \cdot h_{A-nij} \cdot F_{hd_{A-nij}}; \quad (22.14)$$

where: d_{A-nij} – diameter of j tree of i species n years ago, cm

$$d_{A-nij} = d_{Aij}^* - Z_{Dij}; \quad (22.15)$$

d_{Aij} – diameter of j tree of i species during measurement, cm

Z_{Dij} – diameter increment of j tree of i species, cm

$F_{hd_{A-nij}}$ – form factor of j tree of i species n years ago

* Tree diameter at present d_{Aij} is “debarked” using models for the dependence of bark thickness on diameter overbark, while later the diameter d_{A-nij} is “overbarked”

using the functions of bark thickness dependence on diameter underbark (Kuliešis 1985).

$$Z_{Dij} = Z_{rij}/5; \quad (22.16)$$

where: Z_{rij} – radial increment of j tree of i species, mm, measured on sample cores. As far as sample cores are taken only from sample trees, then radial increment for each tree is obtained by regression functions

$$Z_{rij} = a + b \cdot d_{Aij}; \quad (22.17)$$

where: a , b regression coefficients. Having measured ten or more sample trees, coefficients a , b are found by the least squares method.

In other cases

$$a = (1 - b_r) \cdot \bar{Z}_{ri}, \quad (22.18)$$

$$b = b_r \cdot \frac{\bar{Z}_{ri}}{\bar{D}_i}; \quad (22.19)$$

where: b_r – coefficient, changed depending on tree species within 0.45–0.90 range, found as default value (Kuliešis 1985)

\bar{D}_i – mean diameter of i tree species, obtained by formula (22.11)

\bar{Z}_{ri} – mean radial increment of i tree species in a plot

$$\bar{Z}_{ri} = \frac{\bar{Z}_{rai}}{1 - \left[b_r \cdot \left(1 - \frac{\bar{D}_{ai}}{\bar{D}_i} \right) \right]}; \quad (22.20)$$

where: \bar{Z}_{rai} – mean radial increment of sample trees of i species

$$\bar{Z}_{rai} = \frac{\sum_{j=1}^{k_{ai}} Z_{raij}}{k_{ai}}; \quad (22.21)$$

Z_{raij} – radial increment of j sample tree of i species in a sample plot

\bar{D}_{ai} – mean diameter of sample trees of i species obtained analogically to Eq. (22.11) formula

k_{ai} – number of sample trees of i species in a plot

Trees on permanent plots are not bored. Volume increment during the first measurement is estimated by integrating diameters measured in the permanent sample plot with diameters and radial increment of sample trees measured in the same stand, but in the angle count plots, established outside the permanent sample plot.

Tree height n years ago

$$h_{A-nij} = h_{Aij} - Zh_{Aij}; \quad (22.22)$$

where: h_{Aij} – height of j tree of i species at present, estimated by formula (22.7)
 Zh_{Aij} – height increment of j tree of i species, m

$$Zh_{Aij} = \frac{\bar{Z}h_{Ai} \cdot h_{Aij}}{\bar{H}_{Ai}}; \quad (22.23)$$

$\bar{Z}h_{Ai}$ – mean increment of i species trees over n years

$$\bar{Z}h_{Ai} = \frac{\bar{H}_{Ai} - \bar{H}_{A-ni}}{C}; \quad (22.24)$$

\bar{H}_{Ai} – mean height of i species trees at present estimated by formula (22.8)

\bar{H}_{A-ni} – mean height of i species trees n years ago

$$\bar{H}_{A-ni} = f(H_{ABi,A-ni}); \quad (22.25)$$

H_{ABi} – site index, estimated by mean height of i species trees, their present age and a corresponding model (Kuliešis 1993)

$A-ni$ – age of i species trees in a plot n years ago

C – correction coefficient, estimating the difference between mean height changes of trees and height increment due to a mortality of trees less than average ($C \cong 1.12$).

Form factor of a tree n years ago ($F_{hd_{A-nij}}$) is found using tree height and diameter n years ago and is based on a corresponding model (Kuliešis 1993).

Annual increment of a stand storey, tree species and trees of a corresponding state is estimated by summarizing volume increments of trees characterized by respective features and dividing by number of year of remeasurements period.

22.5.4 Increment Structure

Using data for repeated measurements, increment balance for every permanent sample plot is estimated as,

$$Z_M = \Delta_M + M_K + M_O; \quad (22.26)$$

where: Δ_M – volume change, i.e. volume change (during the period between inventories) of trees which comprised the stand n years ago and remained until repeated inventory. Volume change accounts ingrown trees or trees that changed the storey,

M_K – volume of trees felled by intermediate fellings

M_O – volume of dead trees

$$M_O = M_{OK} + M_{O\check{s}} \quad (22.27)$$

M_{OK} – volume of remaining dead trees that will possibly be used in the future

$M_{O\check{s}}$ – volume of dead and salvaged trees in the period between inventories

22.5.5 Estimation of Stand Parameters and Their Variance per Area Unit

For the estimation of stand parameters on a per hectare basis, ratio estimators (Cochran 1963; Kuliešis 1994) or simple expansion methods (Shiver and Borders 1996) are used. These methods are nearly identical when sample plots are of equal areas. For the NFI sampling design, the main sample plot is 500 m² in area, but more than one third of sample plots are divided into sectors. Because the sectors are of varying areas, assessments of their mean values and their variances must be taken into account. For this purpose, the method of weighting mean (Cochran 1963; Гмурман 1972) has been modified, taking into respect the peculiarities of NFI sampling design. In many cases, variance estimation using this method was considerably more efficient than assessment by earlier mentioned methods (Kasperavičius and Kuliešis 2002). The method was used to estimate growing stock volume and other characteristics (increment, number of trees, basal area) on a per unit area basis as well as their variances.

Stand parameters on a per hectare basis, using a modified NFI method, are estimated by the formula:

$$\bar{Y} = \frac{\sum_{i=1}^n Y_i \cdot p_i}{\sum_{i=1}^n p_i}, \quad (22.28)$$

while the variance in total,

$$\sigma_{\bar{Y}}^2 = \frac{\sum_{i=1}^n (Y_i - \bar{Y})^2 \cdot p_i}{\sum_{i=1}^n p_i}; \quad (22.29)$$

where: Y_i – stand parameter value per 1 ha according to i sampling unit

$$Y_i = \frac{y_i}{x_i}; \quad (22.30)$$

y_i – parameter value in i sampling unit

x_i – area of sampling unit, m^2

\bar{Y} – mean of stand parameter per 1 ha of the estimated group of stands, found out by formula (22.28)

p_i – part of sampling unit

$$p_i = \frac{x_i}{q}; \quad (22.31)$$

q – sample plot area equal to $500 m^2$

The variance of the estimate of a stand parameter mean on per hectare basis is,

$$\sigma_{\bar{Y}}^2 = \frac{\sigma_{\hat{Y}}^2}{n}, \quad (22.32)$$

and the standard error of the estimates of means in absolute values is,

$$\sigma_{\bar{Y}} = \sqrt{\sigma_{\hat{Y}}^2}, \quad (22.33)$$

and as a percentage is,

$$P_{\bar{Y}} = \frac{\sigma_{\bar{Y}}}{\bar{Y}} \cdot 100; \quad (22.34)$$

$\sigma_{\hat{Y}}^2$ – variance of stand parameter per 1 ha, ascertained by (22.29) formula

n – number of sampling units – plots, sectors

22.5.6 Estimation of Forest Characteristics in Inventory Object

The growing stock volume of trees, increment and their number for the entire area is estimated as the product of per unit area estimates of these variables and the area of the corresponding group of stands (strata)

$$\hat{Y}_i = \bar{Y}_i \cdot Q_i; \quad (22.35)$$

where \hat{Y}_i – value of inventory index of i stand group

Q_i – area of i stand group, ha.

The standard error of tree volume, increment and their number on the whole area is estimated as,

$$P_{Ti} = \sqrt{P_{\bar{Y}_i}^2 + P_{Q_i}^2}; \quad (22.36)$$

where

$P_{\bar{y}i}$ – error (%) of inventoried parameters of i stand group according to formula (22.34)

P_{Qi} – error (%) of area estimated of i stand group by formula (22.6)

The increment balance of the stand group or stratum is estimated by combining the volumes of all plots represented in this group including the volumes of these trees that were clear cut in the period between inventories. Volume change (Δ_M) in formula 22.26 is divided into two parts – accumulated in the stand (Δ_{M1}) and used (Δ_{M2}) by final cuttings.

22.6 Options for Estimates Based on Reference Definitions

Table 22.5 presents a brief summary of the status of harmonization in Lithuanian NFI. Although some national definitions deviate from COST Action E43 definitions, the estimates can be converted to correspond to the reference definition estimates.

22.7 Current and Future Prospects

Along with operational NFI work, research is continuously carried out to improve the NFI. The main improvements in the NFI are expansion of the assessment indices, increases in assessment accuracy and reliability of indices, a decrease in labor by expanding the use of remote sensing methods, analysis of forest resource dynamics, modeling and improvement of inventory standards, simulating stand growth and formation depending on many factors.

In the near future, inventories of mature stands on large territories using sampling methods are anticipated. Starting in 2008, more attention will be given to

Table 22.5 The availability of estimates based on national definitions (ND) and reference definitions (RD)

Estimate	ND	RD	Responsible
Forest area	Yes	Yes	NFI
Growing stock volume	Yes	Yes	NFI
Increment of growing stock volume	Yes	Yes	NFI
Above- and below-ground biomass	Yes	Yes	NFI, models
Dead wood	Yes	Yes	NFI
Litter	Yes	Yes	NFI, models
Soil	Yes	Yes	NFI, statistics
Afforestation, deforestation, reforestation (Kyoto 3.3)	Yes	Yes	NFI
Naturalness of forest	Yes	Yes	NFI
Forest type	Yes	No	NFI
Occurrence and abundance of vegetation species	Yes	Yes	NFI

inventories of dead wood and wood residuals on cutting areas. The decay stages of dead trees will be assessed up to complete decomposition of wood.

Further modernization of the sampling design is planned so that the data can be used for scenario modeling of forest dynamics, studies to estimate the extent of thinning and other intermediate cuttings, and to guide decisions regarding optimal stand formation. The NFI sampling design will remain unchanged for NFI3 (2008–2012) relative to the design for NFI2 (2003–2007). The second remeasurement of permanent plots is anticipated with the establishment and measurement of the same number of temporary plots as in previous years. The main forest characteristics for the entire country will be estimated annually.

In 2008, the initial assessment of dead wood stages and assessment of stem wood pieces left in felled areas is anticipated. Dead wood will be assessed by the NFI in five decay classes based on newly developed techniques. Assessment of stem wood pieces left on felled areas was already started on an experimental basis in the NFI of 2007. After the improvement of assessment techniques, it will be implemented on whole scale.

Integration of the NFI and Forest Health Monitoring (FHM) Level I measurements will also be started in NFI3. The national network of FHM plots will be moved to coincide with the NFI network, but the existing European grid of FHM plots will be left unchanged for a minimum for 5 years. Therefore, assessment of defoliation of broadleaves will be started on NFI plots during June–August.

A NFI project currently underway is the development of an information system for state control of forest ecosystems. The system includes the continuous inventory program, implementation of silvicultural measures, scenario models, and judicial regulatory acts.

22.8 Implementation of COST Action E43 Results

The successful COST Action E43 has resulted in a considerable improvement of existing assessment methods and development of new assessment techniques used in the Lithuanian NFI. NFI3 was started in 2008. This is the first year for integration of FHM Level I and NFI measurements. Based on results from COST Action E43, assessment of dead wood stages and stem wood pieces left on felled areas was initiated. Dead wood is assessed in five decay classes using new techniques. In the context of COST Action E43, volumes of stumps, tree tops and small diameter trees were estimated which led to improved NFI algorithms and more accurate estimates of growing stock volume. NFI algorithms for international reporting were also developed as a result of COST Action E43.

Harmonization of NFI definitions was very important in the design of new assessment techniques for NFI3 (2008–2012). Most harmonized NFI definitions do not differ considerably from Lithuanian laws, especially Forest law – they broaden our understanding and can be considered during NFI assessments and international reporting. Therefore no legal changes were made.

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