Italian National Forest Inventory: Methods, State of the Project, and Future Developments

Giovanni Tabacchi[1], **Flora De Natale**[2], **Antonio Floris**[3], **Caterina Gagliano**[4], **Patrizia Gasparini**[5], **Gianfranco Scrinzi**[6], **and Vittorio Tosi**[7]

Abstract.—A primary objective of the Italian National Forest Inventory (NFI) is to provide information required by the Kyoto Protocol and the Ministerial Conference on the Protection of Forests in Europe in relation to sustainable forest management practices. For this reason, the second Italian NFI was aimed at providing data in a way that is consistent with the international standards, such as the adopted definition of forest area. Particular attention was paid to the quality of the data collected to obtain good accuracy and high precision at the national level. This has been achieved with a three-phase sampling for stratification that allowed for a high sampling intensity in the first two phases and careful control of the data inputs with continuous feedback from the surveyors.

Introduction

The updating of information on national forest resources is of primary importance for national forest programs and local forest policies. National forest inventories (NFIs) based on statistical surveys provide nations with reliable quantitative forest information.

The first collection of data on Italian forests based on statistical sampling was performed between 1983 and 1985 with the first Italian NFI. The Forest and Range Management Research Institute (ISAFA) designed the project plan and the procedures for data collection and processing, while the field surveys were carried out by the National Forest Service (NFS). The results were published in 1988 (Castellani *et al.* 1988). On the other hand, official statistics on Italian forests were provided by the Italian Institute for Statistics (ISTAT) and derived from annual questionnaires, completed by the NFS. These statistics show few details, particularly on dendrometric and ecological features, and the most recent available data are referred to 1999.

Between 1985 and 2003, local forest inventories at a regional or subregional level were carried out by some administrative regions of Italy. The framework derived from these projects, however, is neither complete, as the local inventories cover only half of the Italian territory, nor homogeneous, because they differ in their sampling schemes, survey procedures, and reference dates.

Therefore, at the end of the 1990s the information on Italian forests appeared to be dated and lacking, especially in meeting the information requirements of international standards. Italy

[1] Project Leader, Consiglio per la Ricerca e la Sperimentazione in Agricoltura, Istituto Sperimentale per l'Assestamento Forestale e per l'Alpicoltura, ISAFA, 38050, Villazzano (Trento), Italy. Phone: +39 0461 381111. Fax: +39 0461 381131. E-mail: isafa@entecra.it.

[2] Researcher, Consiglio per la Ricerca e la Sperimentazione in Agricoltura, Istituto Sperimentale per l'Assestamento Forestale e per l'Alpicoltura, ISAFA, 38050, Villazzano (Trento), Italy.

[3] Forest Technician, Consiglio per la Ricerca e la Sperimentazione in Agricoltura, Istituto Sperimentale per l'Assestamento Forestale e per l'Alpicoltura, ISAFA, 38050, Villazzano (Trento), Italy.

[4] Research Assistant, Consiglio per la Ricerca e la Sperimentazione in Agricoltura, Istituto Sperimentale per l'Assestamento Forestale e per l'Alpicoltura, ISAFA, 38050, Villazzano (Trento), Italy.

[5] Researcher, Consiglio per la Ricerca e la Sperimentazione in Agricoltura, Istituto Sperimentale per l'Assestamento Forestale e per l'Alpicoltura, ISAFA, 38050, Villazzano (Trento), Italy.

[6] Research Manager, Consiglio per la Ricerca e la Sperimentazione in Agricoltura, Istituto Sperimentale per l'Assestamento Forestale e per l'Alpicoltura, ISAFA, 38050, Villazzano (Trento), Italy.

[7] Researcher, Consiglio per la Ricerca e la Sperimentazione in Agricoltura, Istituto Sperimentale per l'Assestamento Forestale e per l'Alpicoltura, ISAFA, 38050, Villazzano (Trento), Italy.

has ratified international conventions and agreements that bind the country to provide information on several aspects of national forests. Italy committed itself to use the criteria and indicators developed by the 2003 Ministerial Conference on the Protection of Forests in Europe (MCPFE) in international reporting on the status and conditions of Italian forests. Furthermore, the agreement of the Kyoto Protocol has bound the Italian government to report on greenhouse gas emissions and, for this purpose, the assessment and monitoring of land use, land use change, and forestry activities is required.

In 1998–99, ISAFA was asked by the Ministry of Agriculture and Forestry to conduct a feasibility study for a new NFI (ISAFA 1999). At the end of 2001, a Ministerial Order instituted a permanent NFI to be carried out by the NFS with the scientific and technical support of ISAFA. The "National Inventory of Forests and Forest Carbon Sinks" (INFC) started in 2002 with the design of the sampling scheme and the survey procedures for the first phase. The inventory design of the INFC is based on a three-phase sampling for stratification, while the previous NFI had adopted one-phase sampling (INFC 2004b). Moreover, the two NFIs differ on the forest definition adopted, the sampling intensity, the distribution of sampling points, and the sources of the data and the attributes surveyed. The old inventory was conducted on approximately 30,000 sample units distributed on a 3 by 3 km systematic grid that were classified as forest or nonforest by field surveys combined with information from available maps. Sample points identified as forest were measured in the field (Castellani *et al.* 1988). The INFC adopted a new sampling scheme to improve the precision of estimates, which meant that it wasn't possible to use the previous NFI's sample points.

Many aspects of the INFC project, such as the survey procedures and the data sources, were designed to meet the international commitments described above. The list of attributes to be assessed was defined with particular attention to the international standards, mainly the United Nations Food and Agriculture Organization definition of forest and also the set of pan-European indicators of sustainable forest management (MCPFE 2003). Many different sources of information were used, such as the national cover of digital orthophotos, national and regional maps, databases and interviews, as well as field data. Lastly, the same framework used for dendrometric measurements is being used for collecting data on many aspects of forest ecosystems, according to a multiresource approach.

Methods

The Sampling Design

The sampling design adopted for the INFC is a three-phase sampling for stratification (fig. 1), in which the first two phases are required to estimate the forest area and its classification into forest categories, while the third is needed to collect dendrometric data (INFC 2004b).

In the first phase, systematic unaligned sampling is used to select sample points to be observed on orthophotos. The first phase sample is formed by approximately 301,000 points distributed on a grid covering the whole Italian territory (30,132,845 hectares), with one sample point drawn randomly within each 1 by 1 km grid square. Through photo interpretation, the sample points are classified by land cover/land use class (fig. 2) to estimate the area of the strata by administrative region, and to identify the sampling units from which the subsamples of the following phases would be selected. The strata derived from the first phase classification are consistent with the first level of the CORINE Land Cover System (European Commission 1993) and with the FAO-Forest Resources Assessment (FRA) 2000 forest definition (UN-ECE/FAO 1997), with a single class including both *forest* and *other wooded land* (OWL) (INFC 2003a). In the second phase, a subsample is randomly selected from the *forest and other wooded land* stratum according to the proportion of the land cover class in the 21 administrative regions of Italy. Approximately 30,000 sample points in the second phase were surveyed in the field to discriminate forest from OWL, to identify different forest types, and to collect information on other qualitative attributes of forest stands (INFC 2004a). The assessment of the main tree species or species group is the basic step to identify the forest type and subtype. On the whole, 23 types and 91 subtypes have been defined (fig. 2) (INFC 2003c). Lastly, a third phase subsample of

Figure 1.—*Diagram illustrating the sampling design adopted by the second Italian National Forest Inventory.*

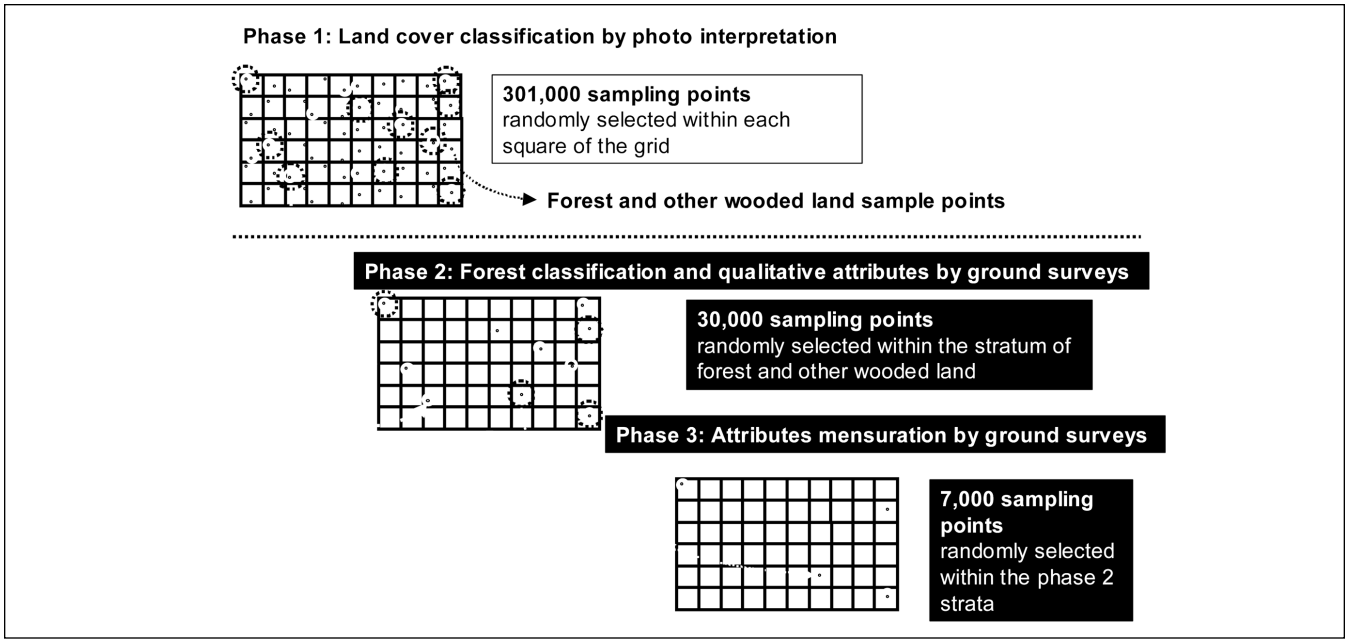
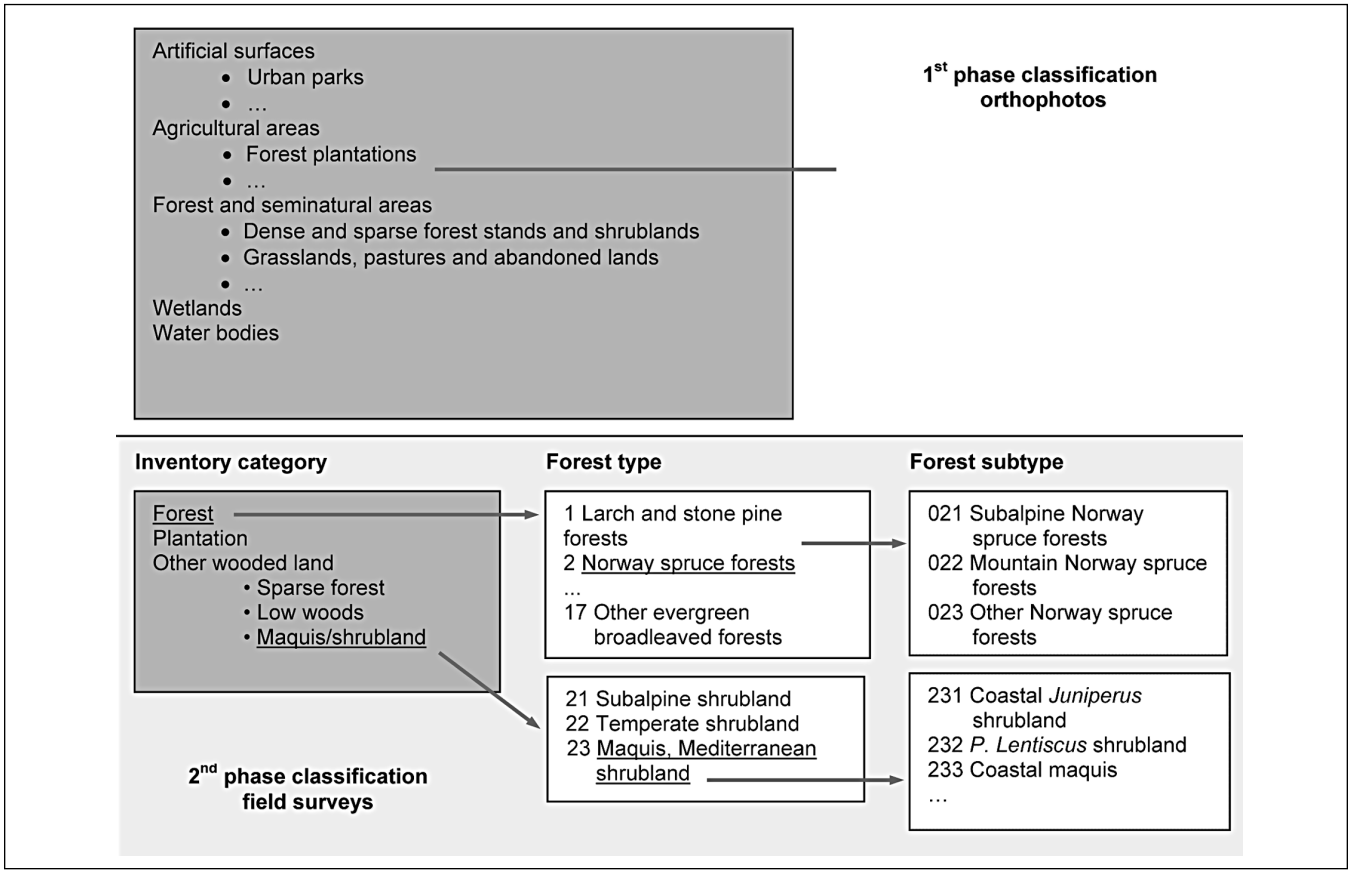


Figure 2.—*Scheme for land cover/land use and forest type classification adopted by the second Italian National Forest Inventory; for the second phase, some examples of forest types and subtypes are given.*



approximately 7,000 points is selected from the second phase sample, then stratified by administrative region and forest type. The third phase subsample is used for dendrometric measurements and for the collection of quantitative data on understory vegetation, dead wood, and other attributes.

Estimation Techniques

As already mentioned, the first two phases are aimed at estimating the area of the inventory strata. The first phase measures the land cover/land use classes and the second phase measures the forest types, both divided by administrative region. The weight of each second phase stratum is derived from the proportion of the first phase sampling points falling in the *forest and other wooded land* class in each administrative region and the proportion of the second phase points falling in each forest type and subtype for the same region. The area of each forest category is then estimated by multiplying its weight by the area of the whole country. The second phase sample is also used to assess the distribution of the forest area according to qualitative attributes (for example property, coniferous trees vs. broadleaves composition, naturalness, etc). The estimators used for area and variance estimates are reported in INFC (2004b) and discussed in Fattorini *et al.* (2004).

For the volume estimation, a new set of 26 models is being developed to predict volume and above-ground phytomass from diameter at breast height (d.b.h.) and total tree height measured in the third phase. In these models, the dependent variables are stem and branch volume, stem and branch dry weight, slash dry weight, dead portion dry weight, stump dry weight, and total above-ground dry weight. To construct these models, approximately 1,300 sample trees from across the country were measured between 2002 and 2005. The models developed for a pilot study area in the eastern Alps are reported in Fattorini *et al.* (in press) and Gasparini *et al.* (2005).

Data Collection and Information Sources

In the first phase, the photo interpretation was carried out by a team of 50 photo interpreters of the NFS working in different regional offices connected to a central database that was continuously updated with the results of the classification. The land cover/land use classes and subclasses were observed on black and white digital orthophotos with a nominal scale of 1:10,000 and a reference date between 2000 and 2003. Photo interpreters used Geographic Information System (GIS) functions implemented within a national GIS, which is a public service with several geographic information strata (cadastral, digital elevation model, land use, ownership, etc.) distributed by a Geographical Area Network or by Internet.

For the second and the third phases, more than 100 crews of two to three people formed by NFS and local forest service personnel were involved in the data collection. Phase two aimed at collecting in-field qualitative information related to forest stands and their ecological features. The field data were taken within a circular plot of 2,000 square metres with the sampling point at the plot center. In addition, administrative information (e.g., ownership, protected areas, restrictions, etc.) are collected by interviews or public database queries, while digital orthophotos are used (on video or in print) to observe the crown cover, the texture (horizontal spatial distribution of trees), and forest edges. For each sample point, approximately 40 forest qualitative attributes, as well as several attributes related to spatial positioning, were recorded (INFC 2004a). In phase three, a number of quantitative attributes will be measured that are related to dendrometric and silvicultural aspects, carbon stock, biodiversity, stand health, and nonwood products. As shown in figure 3, the measurements are taken in different sized plots for each sampling unit. The set of attributes assessed in the Italian NFI, listed by groups and with the indication of the information source, is shown in table 1.

Figure 3.—*Sample plot configuration adopted for the third phase of the second Italian National Forest Inventory, illustrating the different sized plots used to assess the attributes surveyed.*

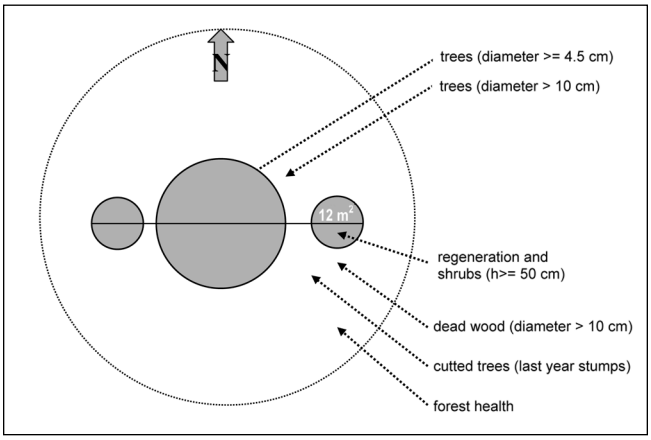


Table 1.—*Set of attributes assessed in the second Italian NFI, listed by groups and with the indication of the information source.*

Attribute group	Source	Attribute	Phase
Land use, land cover	Photo interpretation	Broad land cover classes	I
Forest classification	Field survey	Inventory category, forest type and subtype	II
General information	Field survey, interviews, local laws and regulations, GIS	Ownership, protected areas and other restrictions, forest management, regulations on recreational activities	II
Site information	Field survey	Aspect, slope, local land shape, logging possibilities, natural hazards	II
Stand assessment	Field survey	Stand structure, stand development stage, main species composition, naturalness, microhabitats and artificial infrastructures	II
Road network	Field survey, maps	Roads, logging roads, paths, accessibility	II
Canopy closure and spatial attributes	Photo interpretation	Crown cover class, horizontal structure (texture), forest edges	II
Dendrometric attributes	Field survey	d.b.h., tree height, growing stock (trees with d.b.h. > 4.5 cm), increment, stand age, fellings volume	III
Carbon stock	Field survey	Whole-tree above-ground phytomass, shrub, litter phytomass, organic C soil content (special survey)	III
Biodiversity	Field survey	Tree (and shrub) species, volume and decay rate of dead wood (trees and parts with diameter > 10 cm), saproxilic insects (special survey)	III
Silviculture	Field survey	Type (intensity) of management, cutting method, wood extraction method, regeneration and underbrush (species, density, damages)	III
Forest health condition	Field survey	Primary damaging agent, biotic damages and disturbances assessment, defoliation class	II—III
Nonwood products	Field survey	Presence of special harvesting or picking practices	III
Primary function	Field survey, interview	Primary (or multiple) function assessment	III

d.b.h. = diameter at breast height; GIS = Geographic Information System; NFI = National Forest Inventory.

Data Quality Control

During the first phase, the control of data quality was carried out by the researchers and technicians of ISAFA, who repeatedly checked the classification of the photo interpreters to assure the quality of the final results. From three to eight control samples per region, each one formed by 50 sampling points, were used to test the accuracy of classification during the work. At the end of the first phase, 2 percent of the sampling points were randomly selected and independently reclassified. To compare the classification of ISAFA's and NFS's photo interpreters, quality standards were set for each cover class depending on the importance of the class and on the difficulty of its recognition on orthophotos (INFC 2003b).

For the second phase, control ground surveys were carried out for each region to assure the final quality of the data. Moreover, the data input was checked automatically by the data storage software INFOR2 (Muscaritoli *et al*. 2004), while periodic checks on the data stored in the central database were undertaken to control the consistency of the data and the progress of data collection. A similar procedure is planned for quality control of third phase surveys.

Technology and Data Flow

The great amount of data collected by the INFC required a sophisticated survey system and overall structure for both the database and the data flow.

The following main principles guided the design:

1. Use mobile GIS techniques, with a double client/server architecture and possibility of immediate, safe, and easy data transfer between crew stations and the central server.
2. Ensure the integrity of data through the different phases of the project.
3. Use user-friendly software for personnel without a high level of specialization in computer procedures. Both

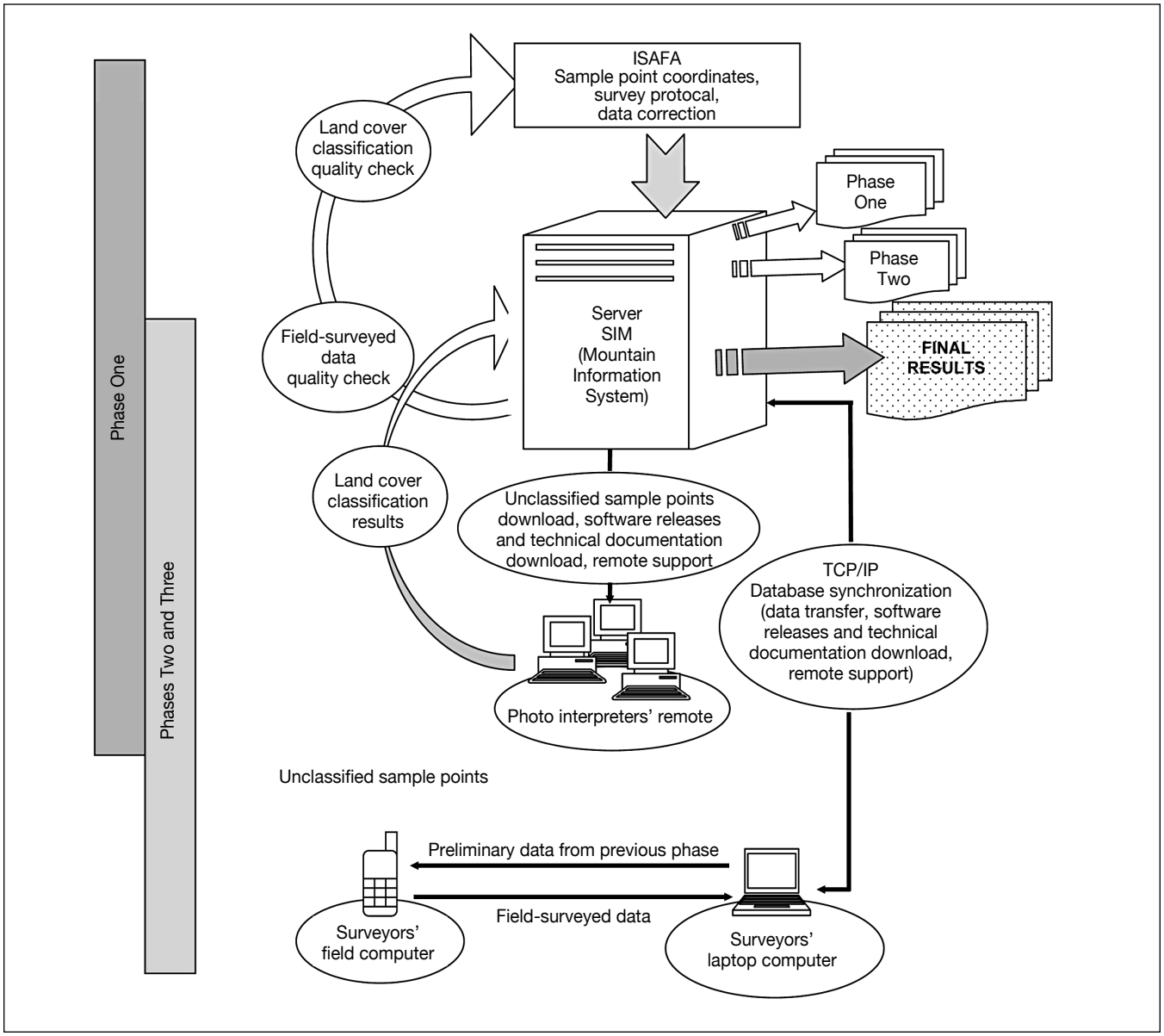
standard software packages (such as ArcPad and IBM DB2) and specifically developed software applications (such as INFOR2 mobile and desktop, and the SIM GISWEB) were used.

4. Integrate between different information sources.
5. Enable remote monitoring of data collection, aimed at early quality control, test, and correction.

During the ground surveys, each crew uses a handheld computer (client) to gather data in the field and a laptop personal computer (client/server) to check, complete, and send the collected data to the central server. Other field instruments used were Global Positioning System (GPS) receivers, digital cameras, laser rangefinders, and more common forest mensuration tools.

Figure 4 shows the dataflow during the different phases of the INFC.

Figure 4.—*Scheme illustrating the data flow of the second Italian National Forest Inventory.*



ISAFA = Forest and Range Management Research Institute.

Ground Positioning Method and Technologies

Because about two-thirds of Italian territory is hilly or mountainous, high-quality GPS receivers were used to acquire accurate measurements under tree coverage and in areas of high relief.

A navigation procedure was defined to avoid any subjectivity in the choice of the field position of the sample point (BCRIC 2001). For this reason, a reference point (F) had to be chosen at a distance of 15 to 25 m from the target sample point (C), in a location suitable for GPS signal reception, collecting a minimum of 180 GPS positions during a maximum time of 15 minutes. Distance and bearing from this point feature (average coordinates) to the target sample point were calculated, allowing for an objective field position of the sample point. A static GPS point (with a minimum of 180 positions) was acquired at the plot center sample point, as well. GPS points were post processed using differential GPS.

Results

The final results of the second Italian NFI are not available at present, as the end of the project is scheduled for 2006. At the moment, the first phase of INFC is finished and the results are published on the Internet (www.ifni.it). The second phase ground survey is almost complete, while the third phase is planned to start in spring of 2006. The final results of the NFI, including quantitative information on the dendrometric features of Italian forests, are expected in the first half of 2007.

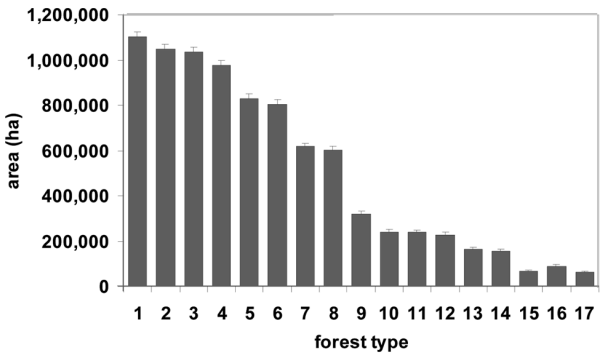
Forest Area, Forest Types Area

The first results of the INFC are shown in table 2 and figure 5 and are based on the first phase data and on the provisional second phase data. These data refer to 78 percent of the sampling points (23,383) that had been already surveyed at the end of March 2005. Table 2 gives the extent of the land cover classes forest and OWL for the whole country with their standard errors. Concerning the forest area by administrative regions, a high precision of estimates was obtained thanks to the sampling design and the high number of sampling points surveyed in the first two phases of the NFI. The standard error of estimate was 1.12 percent for Toscana, one of the larger administrative region of Italy with the largest forest area (the provisional estimate of forest plus OWL area is 1,156,682 hectares and the total area of the region is 2,298,448 hectares). Puglia and Valle d'Aosta had standard error of estimates of 3.96 and 3.38, respectively. Puglia is the region with the smallest proportion of forest (approximately 8 percent of the regional territory) and

Table 2.—*Provisional estimates of forest and other wooded land area provided by the second Italian National Forest Inventory*.

Land use	Area (ha)	Standard error (%)
Forest	8,767,720	0.43
Other wooded land	1,662,099	1.76

Figure 5.—*Provisional area estimates for the 23 Italian forest types defined for the second Italian National Forest Inventory.*



1 Oak forests (*Quercus petraea* (Matt.) Liebl. , *Quercus robur* L., *Quercus pubescens* Willd.)
2 Oak forests (*Quercus cerris L., Quercus fraineto* Ten., other oak species)
3 Mixed deciduous broadleaved forests
4 Beech forests (*Fagus sylvatica* L.)
5 Chestnut forests (*Casatnea sativa* Mill.)
6 Hornbeam forests (*Carpinus spp., Ostrya carpinifolia* Scop.)
7 Norway spruce forests (*Picea abies* (L.) Karsten)
8 Holm oak forests (*Quercus ilex* L.)
9 Larch and stone pine forests (*Larix decidua* Miller, *Pinus cembra* L.)
10 Mediterranean pine forests (*Pinus domestica* L., *Pinus maritima* Miller, *Pinus halepensis* Miller)
11 Hygrophilous forests
12 Black pine forests (*Pinus nigra* Arnold, *Pinus laricio* Poir., *Pinus leucodermis* Ant.)
13 Coark oak forests (*Quercus suber* L.)
14 Scots pine (*Pinus sylvestris L.*) and Mountain pine (*Pinus uncinata* Mill.) forests
15 Fir forests (*Abies alba* Mill.)
16 Other evergreen broadleaved forests
17 Other coniferous forests

Valle d'Aosta is the smallest region of Italy (325,121 hectares as provisional estimate of forest plus OWL area).

As explained in the description of the sampling design, the forest type was classified in the field on the basis of the prevailing tree species or species group in the sample plot. Figure 5 gives the provisional results on the proportion of the different types of Italian forests. The standard error of estimates calculated from the provisional data are quite small, ranging from 1.9 to 2.1 percent for the largest strata, the extent of which is approximately 1,000,000 hectares (*Oak forests*, *Beech forests*), to 2.6 to 2.8 percent for middle-sized strata of approximately 600,000 hectares (*Norway spruce stands*, *Olm oak forests*). The standard errors for the smallest strata are 8.8 percent for *Other coniferous forests* (approximately 63,000 hectares) and 8.6 percent for *Fir forests* (approximately 65,000 hectares).

Positioning Accuracy

The following positioning data are based on about 93 percent of the total sample. If we exclude nonforest (6 percent) or unapproachable[8] (13 percent) points, as well as points with technical problems on the GPS files (1.4 percent), we have positioning data on about 80 percent of the surveyed sample.

Table 3 shows the distribution of the data according to classes of distance between field and theoretical coordinate values of the sample points. These distances can be considered an accuracy index of the field positioning. Our results are promising in that the average distance value was 2.73 m.

An earlier study carried out by the ISAFA (Scrinzi *et al*. 2003) on GPS performances in INFC conditions had estimated expected accuracies within 8 m (standard GPS mode, 90 percent probability level). According to INFC field survey results, roughly 93 percent of the data are within the expected accuracy. The upper class (> 30 m) includes very high and improbable values, which can be thought of as outliers; for this reason they have been excluded from the average calculation and will need further processing.

Table 3.—*Distribution of the second phase sampling points by class of distance from their nominal position.*

Distance classes (m)	Frequency (number of points)	Frequency (% of points)
No data	560	2.52
≤ 2	10,432	46.85
> 2 to 5	8,441	37.91
> 5 to 8	1,875	8.42
> 8 to 15	640	2.87
> 15 to 30	123	0.55
> 30	194	0.87
Total	**22,265**	**100.00**

Concerning the operational performances of GPS, the system failed to collect positions on the sample point location in only 2.5 percent of cases. Failures were due mainly to severe topography and high tree coverage conditions. Alternative navigation procedures (compute-aided traverse path by means of conventional techniques) were necessary only in 24 cases (0.11 percent).

Discussion

One of the main aims of the new Italian NFI is to produce information needed for international reporting activities such as FAO assessments, carbon sink estimates for the Kyoto Protocol reporting, and the production of national reports on the sustainability of forest management within the MCPFE process. Therefore, by defining the inventory domain and the survey procedures of INFC, particular attention was paid to the international standards and commitments. It has been decided to base the inventory domain on the FAO-FRA 2000 definitions and to include both forest and other wooded land use. Moreover, besides the more traditional dendrometric and silvicultural attributes, the data collection involves more detailed measurements about above-ground phytomass and ecological features to provide data on carbon sequestration and to meet most of the commitments related to the MCPFE.

[8] **Unapproachableness** of a sample point could be declared, by the crew, according to the following criteria: crew safety (first priority), permission denied in private properties, and impenetrable vegetation. Most of the unapproachable points were remotely observable and therefore used for main forest type classifications.

In relation to the carbon stock estimates, the INFC provides our country with updated and reliable data on the extent of forests, on the volume and the dry weight of above-ground phytomass and dead wood, on growth rate, and on the carbon content of litter and organic soil. Concerning the indicators of sustainable forest management, the INFC data enable us to provide information on 20 of the quantitative pan-European indicators of sustainable forest management (table 4). The remaining indicators are not suitable to be assessed by an NFI as they involve aspects that are either not observable by sampling procedure or require very detailed and time-consuming surveys.

A second important goal of the inventory project is to assure the quality of the data collected to obtain a good accuracy and a high precision of results at the national level. This has been achieved both by defining a suitable sampling design and

Table 4.—*Attributes of the second Italian National Forest Inventory and their consistency with the pan-European indicators of sustainable forest management*.

Criterion	Quantitative indicator	Consistency with MCPFE standards
1 Maintenance and appropriate enhancement of forest resources and their contribution to carbon cycle	1.1 Forest area	Yes
	1.2 Growing stock	Yes
	1.3 Age structure, diameter distribution	Yes
	1.4 Carbon stock	Yes, but no measurements on below-ground phytomass
2 Maintenance of forest ecosystem health and vitality	2.1 Deposition of air pollutants	No
	2.2 Soil condition	Partly: organic C content only
	2.3 Defoliation	Yes
	2.4 Forest damage	Yes
3 Maintenance and encouragement of productive functions of forests	3.1 Increment and fellings	Partly: no data on natural losses and on annual fellings for d.b.h. < 20 cm
	3.2 Roundwood	Partly: data on roundwood with d.b.h. > 20 cm; no data on marketed volume and value
	3.3 Nonwood goods	Some qualitative information
	3.4 Services	Some qualitative information
	3.5 Forest under management plans	Yes
4 Maintenance, conservation, and appropriate enhancement of biological diversity in forest ecosystems	4.1 Tree species composition	Yes
	4.2 Regeneration	Yes
	4.3 Naturalness	Yes
	4.4 Introduced tree species	Yes
	4.5 Deadwood	Yes
	4.6 Genetic resources	No
	4.7 Landscape pattern	Partly: information on texture and forest edges
	4.8 Threatened species	No
	4.9 Protected forests	Yes
5 Maintenance and appropriate enhancement of protective functions in forest management	5.1 Protective forest extent (for soil and water protection)	Yes
	5.2 Protective forest extent (for infrastructure protection)	Yes

Table 4.—*Attributes of the second Italian National Forest Inventory and their consistency with the pan-European indicators of sustainable forest management (continued)*.

Criterion	Quantitative indicator	Consistency with MCPFE standards
6 Maintenance of other socioeconomic functions and conditions	6.1 Number of forest holdings	No
	6.2 Contribution to gross domestic product	No
	6.3 Net revenue of forest enterprises	No
	6.4 Expenditures for services	No
	6.5 Forest sector workforce	No
	6.6 Occupational safety and health	No
	6.7 Wood consumption	No
	6.8 Trade in wood	No
	6.9 Energy from wood resources	No
	6.10 Accessibility for recreation	Yes
	6.11 Cultural and spiritual values	No

MCPFE = Ministerial Conference on the Protection of Forests in Europe.

monitoring data collection and data storage. The three-phase sampling design for stratification, with the interpretation of orthophotos in the first phase and expeditious ground surveys in the second phase, made it possible to use a large sample size, which assures a high reliability of inventory results. Indeed, the provisional estimates of forest and other wooded land area presented in this paper are very precise, with low percent standard errors. Forest type area estimates at national scale follow the same trend, with percent errors of less than 3 percent for most types considered. It should also be noted that our procedures allowed for accurate spatial positioning of samples with average distance errors of less than 2.8 m.

As a consequence of its ambitious aims, the NFI project requires a great effort, both from an organizational and from a technical point of view. Among the different aspects of the inventory, the technical support together with the monitoring of the data flow required quite a sophisticated survey system. The management of the data flow and the database is indeed one of the most critical issues of this project, due to the large amount of data coming from many different parts of the country and the large number of people involved.

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