Chapter 13
Chile

Carlos Bahamondez, Marjorie Martin and Yasna Rojas

13.1 The Chilean National Forest Ecosystem Inventory (NFEI)

13.1.1 Historical Aspects and Objectives

Chile has applied permanent inventory techniques since the 1980s. However, an important precursor to this occurred much earlier in 1944–45 when the Chilean government in cooperation with the USDA Forest Service completed a project titled “Forest resources of Chile, basis for industrial expansion” (Haig 1945). This project was the first application of inventory techniques in Chile and latin America, which promoted new developments such as the use of aerial photos as a base for mapping. The project also developed the capacity of professionals working in forestry. Among other positive effects this first inventory highlighted serious concerns about the sustainability of forests at that time. Unfortunately, this initiative was not designed to provide permanent monitoring and no continuous forest inventory was established at that time.

The focus of the 1944 forest inventory was on wood supply and production potential given the state and condition of forests at that time. Nowadays the paradigm of reporting on growing stock has moved to a multifunctional concept, to address the sustainability of forests ecosystem after Brundtland commission (1987) and the Rio Summit in 1992. All the conventions and agreements existing today are

C. Bahamondez (✉) · M. Martin · Y. Rojas
Forest Research Institute (INFOR), Valdivia, Chile
e-mail: cbahamon@infor.cl

M. Martin
e-mail: mmartin@infor.cl

Y. Rojas
e-mail: yrojas@infor.cl

C. Vidal et al. (eds.), *National Forest Inventories*,
DOI 10.1007/978-3-319-44015-6_13

the result of processes such as, the United Nation Framework Climate Change Convention (UNFCCC), the Convention on Biodiversity (CBD) and the various forest agreements such as the Montreal Process, the Helsinki Process (currently FOREST EUROPE) and others.

In fact, all these organisations are periodically requesting countries to provide data and information related to ecological, economical and social issues of their forests resources. Given the wide range of information required, it is clear the necessity of a large scale forest ecosystem inventory at national level.

13.1.2 Sampling Methods and Periodicity

The total area of Chile is 75.6 million ha, of which forests occupy 16.5 million ha. Natural forest cover 13.5 million ha. The difference are mainly plantations of *Pine* spp. and *Eucalyptus* spp. forests. The Chilean National Forest Ecosystem Inventory (NFEI) was designed to satisfy the national and international demand for data and information with regard to the ecosystem as a whole. The design considered bio-physical, biodiversity and socioeconomic issues under a multilevel and multisource inventory design (Scheuder et al. 1993). The NFEI aims to further secure the forest ecosystem integrity by tracking through time the state and condition of a set of key monitoring elements.

Sample plots are located on a systematic sampling grid, 5 km in the East-West and 7 km in the North-South directions (INFOR 2014). This grid was a result of a specific autocovariance study performed in 1995 to decide objectively the best grid layout for the whole country. The sample unit used is a cluster of three circular sample plots of 500 m^2 organized as nested circular sample plot for efficiency reasons. To increase the efficiency of field data collection three sample units are taken on an inverted "L" shape, where the vertex corresponds to the sample unit 1 according to Fig. 13.1.

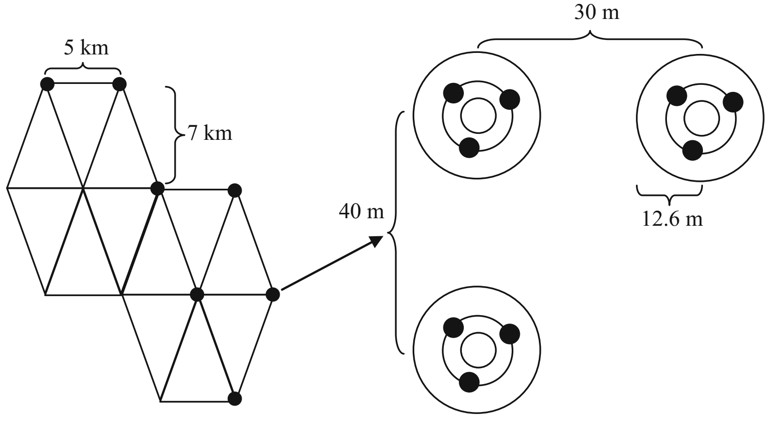

Fig. 13.1 NFEI sampling design details

Field measurements are performed on a 4 year cycle where every year one quarter of the field plots are assessed annually. Annual estimates are calculated by combining new ground truth data, remeasured sample plots and corrected projections for those plots not visited in previous year. Correction is based on a calibration generated by the remeasurement plots (Kangas 1991).

The nested disposition of the circular sample plot (Fig. 13.1) consists of three concentric circles of fixed radius associated to trees sizes, the largest radius of 12.62 m, involves trees larger than 25 cm of diameter at breast height (dbh), trees with dbh > 8 cm are measured within the radius of 6.23 m and trees with dbh > 4 cm are in a radius of 2.0 m. The three small solid circles correspond to vegetation and regeneration and soil subplots.

13.1.3 Data Collection

The rationale of the forest ecosystem inventory in Chile is based on a requirement for national and international data about ecosystem as a whole. That means the design of the inventory considers biophysical, biodiversity and socioeconomics issues. Its goal is to monitor the integrity of the forest ecosystem and ecosystem stressors as the key elements to collect.

As a conceptual framework the four stages decribed by Holling (1973) (Liberation, Organization, Exploitation and Conservation) are used as guidance during the planning stage to identify suitable variables to explain the natural dynamics of forest ecosystems.

A hierarchical approach (Kay 1984) to the forest ecosystem was applied identifying those key elements at several temporal and spatial scales. The resolution of what is operationally measurable is in line with our technological capacity of detecting changes, which are usually described annually. Basically, a hierarchic system was devised according three operationally measurable levels (Fig. 13.2) tree level, trees and neighbours and, stand level. Given the resources available, these levels represent the best selection of variables at both temporal and spatial scale. The decision on the final variables to collect in the field was made possible through the use of stepwise regression analysis.

The main variables collected during field work are described below:

Tree level: Measurement on trees at stem and crown level involves dbh, bark thickness, health status, types of damage or disease, causing agent, crown diameter, crown dominance according to Kraft (1884), crown health and relative location. From all the trees selected according to the concentric plot arrangement, detailed measurements on species commercial height, total height, height at the origin of the crown canopy, the height to one third of the total height are collected from the sample trees of the different concentric plots. Similarly, the diameters at the aforementioned heights are measured. Additionally, dbh growth is measured by core extraction. Within the three circular subplots of 1.0 m^2 each one (Fig. 13.1),

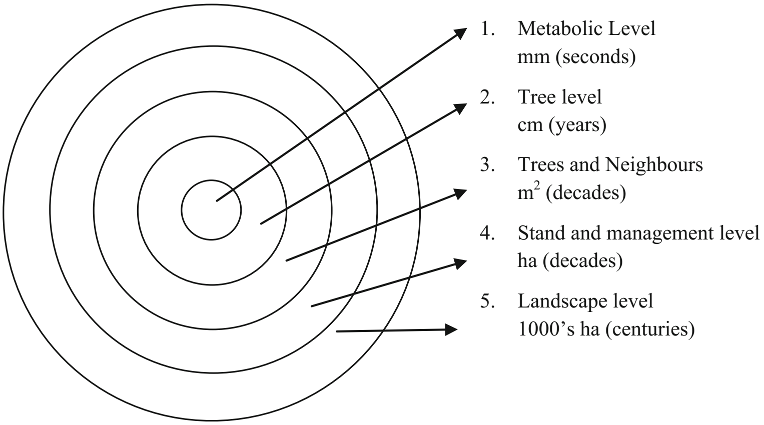

Fig. 13.2 Hierarchical approach to ecosystem, measurable levels were defined as level 2, 3 and 4 (between brackets the units and temporal scale of each measurement)

vegetation, and regeneration are assessed. Each tree is assessed for the presence of nests or similar features.

Trees and neighbours level: this level concerns the tree and its imediate competitors, thus, the issue of competition, mutualism and growth capacity is relevant. A description of the management is recorded, mainly type, intensity, state, the relative position of trees with their neighbors, the origin (coppice or seed), topographic variables like slope, geomorphology and orientation, signs of grazing, water, erosion, drainage, endangerous flora, fauna, buildings, high religious area or etnic valued area are some of the data collected.

Taking advantage of the cluster spatial arrangement, coarse woody debris (lying trees pieces with intersection diameter >10 cm) and fine woody debris (pieces with diameter <10 cm) are sampled by applying line intersect sampling, using an imaginary line connecting the subplot centers.

As well as woody debris, standing dead trees and stumps are also measured, using the same plots and rules applied to living trees. Dead trees are important for the nutrient cycle and they relate to habitat or shelter provision for the fauna and microfauna.

Biomass is also relevant to the amount of fuel or nutrient stored in the forest, but also allows for $CO_{2\text{-eq}}$ estimations in several pools.

Stand level: the cluster is used as an indicator of landscape dynamics with a focus on soil, which is sampled in plot 1 of the cluster. Among soil variables, color, pH, depth, depth of humus and litter, texture, structure, humidity condition, presence of worm, roots and micorrizes, compactation, fertility and erosion are recorded. Furthermore, a general description is added reflecting signs related to the degree of human intervention, degradation status and biotic, abiotic, cultural-ethnic and social drivers dominating the sample plot. Regeneration is also depicted for the cluster as a proxy of the forest sucessional stage. Lichens, shrubs and some herbaceous are collected mainly as potential site quality indicators.

At landscape level, biodiversity as life support for the ecosystem is monitored by collecting data on: plants, mammals, arthropods, reptile, birds and fungus based on a hexagonal unit of 269,000 ha, containing close to 50–70 clusters previously stratified according to Holling stages. Trap cameras and field sound and ultrasound recorder are installed in the field to record mainly species abundance. Reptiles and arthropods are sampled in line sampling. The goal for this level is to collect evidence on forests species or species together with non Plantae reigns species, in order to get a thorough understanding of management effects on these forest dependant species.

13.1.4 Data Processing, Reporting and Use of Results

The NFEI was not designed to assess land use changes and land classification. This task is performed, using a wall to wall approach officially undertaken by the Chilean Forest Service (Corporacion Nacional Forestal, CONAF). Thus, the NFEI takes the estimated CONAF areas as a base for its volume and biomass approximations to country level.

The volume and consequently biomass are processed using the following steps:

1. Field data collection
   At this stage, the data are stored in the field data logger which includes a set of validation rules controlling data consistency and quality.
2. Upload to database
   This stage consists of loading the field data from the data logger to the NFEI database. At this step, a second validation of consistency is performed by applying database engine specific stored procedures. The database engine utilised by the NFEI corresponds to an SQL Server over a normalised data model.
3. Tree processing
   Individual tree calculation is the core element in processing statistics. Firstly, a visual and graphical inspection of data is performed. Then, several procedures for the detection of unusual tree variable relationships are applied, e.g. the subplot relation diameter at breast height versus height, analysis of consistency between diameters at different heights, checking for errors in attribute classification. Once the data quality is approved, several volume and biomass functions available by species are applied to the several selected trees in every concentric plot of the cluster.
4. Plot and cluster processing
   The cluster of the three 500 m^2 plots, constitutes the sample unit. Thus, the aggregated results from the cluster plots are the statistical valid results for inventory precision estimation.

5. Tables and maps
   The usual tables with several entries like forest types, administrative arrangements like regions, provinces or communes, and combinations among them are produced as results. Additionally, by applying *k-nn* algorithm on samples aided by satellite images (Tomppo 1990), a set of national thematic maps are generated for volume/ha, basal area/ha, number of trees/ha, above ground live biomass/ha, above ground dead biomass/ha, carbon/ha, growth/ha, among others.
   No drain estimation is performed given that only first cycle data are available. The second cycle will commence in 2015.

13.2 Land Use and Forest Resources

13.2.1 Land Use Classification and Designation

The classification of lands established by CONAF during 1993–1997 applied a Montpellier approach known as “Carta de Ocupación de Tierras” (COT) to produce a forest map at a resolution of 6.25 ha, including a forest type delineation.

According to national definition, a forest is a portion of land with a minimal area of 5000 m^2 with a potential height of trees larger than 2 m, and crown cover larger than 25 %. FRA Classes like and Trees Outside the Forest (TOF) are not measured. The results of this national classification expressed as FAO classes (FAO 2010) are presented in Table 13.1.

Table 13.1 Land use areas for national classes and FAO classes (1000 ha)

National classes	Forests	Other wooded land	Other land	Water (inland)
Urban			230.5	
Agriculture			3674.1	
Pasture			5858.3	
Shrubs-pasture		2515.5		
Shrubs		8632.6		
Shrubs-trees		1667.3		
Shrubs-arid		1824.0		
Arid vegetation		63.6		
Shrubs-plantation		45.2		
Forests	16,231.0			
Wetland			4496.2	
Bare land			24,621.8	
Glacier and snow			4505.9	
Water inland				1229.2
Non recognised			399.7	

Table 13.2 Forest area by primary management objective

Management objective	Description	Area (1000 ha)
Production	Devoted to wood production and similar like fibre, bioenergy and non wood forest products[a]	7485
Protection	Soil protection and riparian areas	4714
Conservation	Mainly biodiversity protection	2320
Multiples uses	Several uses on production	1712
		16,231

[a]This is a potential productive resources from natural forests, given more than 90 % of industrial production in the country come from forest plantations

In relation primary management objective of the forests, Table 13.2 details the forest area by FAO management objective classification. Recently a law to promote natural forest management was enacted. Its effects on natural forests has yet to materialise. While management and cutting regulations are in place, few management plans are proposed for approval to the authorities.

13.2.2 *Wood Resources*

The growing stock associated with natural forests and its increment are calculated from the sample units defined as a cluster of three 500 m^2 plots. Available volume and biomass functions consider only trees with dbh > 8 cm. Table 13.3 depicts national definitions and threshold considered for calculation.

An estimate of drain is still not reliable given the lack of data on natural losses from the field. Currently, cutting removals and household fuelwood consumption statistics are available. However, the fuelwood statistics underestimate the true extent of felling as at least 70 % of trade in fuelwood is not accounted for. It is expected the drain will be reported after the end of second cycle of NFEI. The resulting assessment on natural forest from data processing is detailed in Table 13.4 by Chilean administrative regions.

The total 2014 stock of forest in the country rise to 3.4 billion m^3 in a total area of natural forests of 13.4 million ha. Every year the forest growing stock increases

Table 13.3 Detailed related growing stock national definitions

Variable	Definition
Standing stock	Volume of trees with dbh > 8 cm including bark and full stem, excluding above ground piece of the stump
Increment	Volume of trees with dbh > 8 cm over bark taken by bore extraction
Drain	Drain is defined as the sum of cutting removals, household fuelwood consumption, natural losses and waste estimation. In this respect currently, NFEI is still not able to provide reliable estimate of drain

Table 13.4 Current estimates of the natural forest area, volume, growing stock and growth by region

Region	Forest area (1000 ha)	Growing stock (m^3/ha)	Growing stock (1000 m^3)	Increment (1000 m^3/y)
Coquimbo	3.5	28.79	101.1	–
Valparaíso	95.4	21.16	2019.9	–
Metropolitana	93.5	28.21	2638.7	–
O'Higgins	118.0	36.43	4299.1	–
Maule	370.3	161.54	59,823.1	1527.8
Bio Bio	786.2	172.62	135,715.2	6965.4
Araucanía	908.5	290.6	264,010.4	5689.2
Los Ríos	850.0	357.43	303,815.5	5389.3
Los Lagos	2758.8	265.36	732,100.5	6782.5
Aysén	4814.0	266.32	1,282,082.0	24,118.7
Magallanes	2625.5	248.17	651,571.8	7181.0
Total	13,424.0		3,438,171.3	57,654.2

by 57.6 million m^3. The current lack of drain estimates do not allow the calculation of forest balance to be assessed until the second cycle of the inventory be completed. The distribution of growing stock by forest type and administrative region is provided in Table 13.5.

Table 13.5 Distribution of growing stock by forest type and administrative region (million m^3)

Forest type	Region						
	Maule	Bio Bio	Araucanía	Los Ríos	Los Lagos	Aysén	Magallanes
Fitzroya cupressoide					39.14		
Nothofagus dombeyi Nothofagus alpina, Laurelia phillippiana			37.31	135.67	537.65		
Quillaja saponaria, Peumus boldo	7.18						
Nothofagus dombeyi, Nothofagus alpina, Nothofagus obliqua	23.33	88.17	79.62	51.8	37.83		
Nothofagus glauca, Nothofagus obliqua	26.92						
Other forest types		25.95	27.64	51.56		5.44	
Araucaria araucana		7.64	119.46				
Austrocedrus chilensis		3.29					
Other forest types		0.75		64.78	114.22	1124.45	
Nothofagus pumilio		9.88				104.2	651.57

13.3 Asessment of Wood Resources

13.3.1 Wood Supply and Wood Quality

Nothofagus dombeyi, *Nothofagus alpina*, *Nothofagus oblique*, evergreen and *Nothofagus pumilio* forest types are among the most relevant forest types for future productive use. Natural forests in Chile are currently not the cornerstone of industry, which mainly supported plantations of *Pine* and *Eucalyptus* species. There are important barriers and issues to be solved before these forest types become a productive alternative satisfying the internal and international market, including:

1. Irregular status of land tenure. By law any landowner must show legal status of their property and once demonstrated, permission to cut and management are provided. Unfortunately, a large amount of natural forest landowners have no tenure, which consequently results in illegal logging, degradation and unsustainable practices.
2. Forest location. The majority of forest are geographically located in areas with very poor accessibility. It is not economically viable to transport this timber to any plant or industrial facility. Another element to this is the geomorphology of forest areas, steepy areas dominated by Andean Range limits harvesting operations.
3. Irregular forest structure. The current forest structure is highly irregular, showing an age and size structure not suitable to sustain a stable wood product flux through a certain time horizon, usually 20–30 years.
4. Forest is being degraded. Every year more than 9.0 million m^3 is cut illegally for the fuelwood market, as this activity is not regulated by a management plan the forest is shown to be degraded, according to field observations.
5. Interest rate too high. An interest rate of 8 % is required to borrow funds for forest related projects, which is far from the 3 % return from economic activity in natural forests. In order to sustain such a rate, forest products need to be valued by management and focus in high quality wood products.
6. Cattle grazing. Cattle grazing whithin the forest results in strong soil compactation, destroys regeneration and opens the understory to borer insects. Insects destroy the first log of the tree causing a number of galleries declassifying the log. As a result, only 9 % of volume/ha classify as high quality, 21 % is lost volume because of damage and disease, and the remaining volume is medium to low valued material.

13.3.2 Change Assessment

The NFEI is treated as a continuous forest inventory, where two successive inventories are combined to assess change through time. In general two alternatives

Table 13.6 NFEI continuous forest inventory cycle

Zone id	Year 1	Year 2	Year 3	Year 4
Zone 1	Remeasure	Project_{t+1}	Project_{t+1}	Project_{t+1}
Zone 2	Project_{t+1}	Remeasure	Project_{t+2}	Project_{t+2}
Zone 3	Project_{t+2}	Project_{t+2}	Remeasure	Project_{t+3}
Zone 4	Project_{t+3}	Project_{t+3}	Project_{t+3}	Remeasure

are available, (i) using permanent sample plots or (ii) using temporal sample plot. In this case, the NFEI apply permanent sample plots with partial replacement. The whole country is divided in four zones which are assessed over a 4 year period. Continuous estimates are coming from remeasurement 25 % of the available sample unit belonging to the respective zone and, measured during the first cycle. As a means to maintain an updated inventory for the whole country, a projection of growing stock based on sample units is performed in those zones where no remeasurement is performed. The inventory cycle is detailed in Table 13.6. As Table 13.6 shows, the cycle of remeasurement and projection of growing stock, facilitates the annual updating for the whole country. Remeasurement, provides data on the trends of growing stock at the level of a sample unit, but also, provides data about the quality of projection by modeling. It also allows for correction algorithm to be generated which are used to improve estimates (Kangas 1991; Dixon and Howitt 1979).

References

Brundtland Report of the World Commission on Environment and Development: Our Common Future (1987) www.un-documents.net/wced-ocf.htm. Accessed 15 Feb 2016

Dixon B, Howitt R (1979) Continuous forest inventory using a linear filter. For Sci 25:675–698

FAO (2010) Evaluacion De Los Recursos Forestales Mundiales 2010—Informe Nacional—Chile, pp. 1–64. http://www.fao.org/docrep/013/al477S/al477S.pdf. Accessed 14 Mar 2016

Haig M (1945) Forest resources of Chile, basis for industrial expansion final report

Holling CS (1973) Resilience and stability of ecological systems. Annu Rev Ecol Syst 4:1–23

INFOR (2014) Los recursos forestales de Chile. Final report 2014. pp 1–273

Kangas A (1991) Updated measurement data as prior information in forest inventory. Silva Fenn 25(3):180–191

Kay JJ (1984) Self-organization in living systems. Department of Systems Design Engineering, University of Waterloo, Waterloo

Kraft G (1884) Beiträge zur Lehre von den Durchforstungen, Schlagstellungen und Lichtungshieben [Contributions to the science of thinnings, coupe designs and interventions for light management]. Hannover

Loetsch F, Haller, KE (1964) Forest inventory: statistics of forest inventory and information from aerial photographs (vol I). BLV Verlagsgesselschaft, Munchen

Matern B (1960) Spatial variation. Stochastic models and their application to some problems in forest survey and other sampling investigations, pp 1–144

Scheuder HT, Gregoire T, Wood G (1993) Sampling methods for multiresource forest inventory. Wiley, NY

Tomppo E (1990) Satellite image-based National Forest Inventory of Finland. Photogram J Finl 12 (1):115–120

UN (1992) Rio earth summit: summary of the United Nations conference, annual Report