Chapter 18
Ecuador

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18.1 The Ecuadorian National Forest Inventory

18.1.1 History and Objectives

Ecuador's National Forest Inventory (NFI) is the main component of its National Forest Assessment (NFA) which emerged in 2009 as an initiative led by the Ministry of Environment of Ecuador (MAE). The NFA received technical support from the Food and Agriculture Organization of the United Nations (FAO), through the Sustainable Forest Management in the Face of Climate Change project and financial support from the Government of Finland. The NFA was devised to generate the information required to plan for the sustainable management, harvest and conservation of Ecuador's native forest resources (Aguirre et al. 2010). This methodological and technical process was Ecuador's first experience with forest planning at a national scale.

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There have been past efforts, from the 1960s to the 1980s, to assess Ecuador's timber resources. Those assessments, although compiled nationally, were undertaken at the regional and local levels. They focused on particular objectives, but without standardised methodologies.

The last three important forest inventories completed in Ecuador occurred in the 1960s, 1970s and 1980s. The first one focused on the northwestern Ecuador in the province of Esmeraldas; the second one focused on the forests of southern of the country; and the third one and last forest inventory focused on the central portion of the Ecuadorian Amazon. The main objectives of these subnational forest inventories were related to timber harvesting, floristic composition, monitoring of plant diversity and interpretation of satellite images and aerial photographs of the sampling areas.

The promoters of these first steps related to forest inventories in Ecuador included institutions such as: UN agencies, national and international NGO's, Center for Integrated Natural Resource Remote Sensing (CLIRSEN) and the National Forestry Directorate (DNF) which at that time belonged to the Ministry for Agriculture, Livestock, Aquaculture and Fishing (MAGAP) (Aguirre et al. 2010).

Subsequently, the need to have robust and current national information about forest resources was recognised It was seen as an essential tool to facilitate the development of the forest sector nationally. In May 2006, the DNF planned the NFA with three main components: (1) NFI, (2) Carbon density maps and (3) socio-economic components.

In this context and under the mandate of MAE, the NFA was initiated as a multipurpose tool with the capacity to: (i) provide data and information for decision-making and policy development for sustainable forest management, (ii) respond to requirements for access to international carbon markets, (iii) facilitate periodic long-term monitoring and (iv) offer flexibility and adaptability for future information needs (Aguirre et al. 2010). These requirements were framed within one of the main goals of the Forest Governance of Ecuador related to the "Generation of Forestry Information" (MAE 2011).

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The NFA is the first effort in Ecuador that defines primary inputs of information related to native forests that considers multipurpose objectives and long term planning. Also, it was the only one done at the national scale with standardised methodologies. Its results provide baseline forest information and identifies new questions related to native forests research and management. The structure of the NFA allows periodic updating of information.

18.1.2 Sampling Methods and Periodicity

The NFI uses a stratified random sampling scheme, based on a 1 × 1 km grid of points within forest type strata. At each grid point, a cluster with three subplots was established. A pilot forest inventory was conducted and 40 sampling units (SU) were completed, distributed across two strata: Andean Dry Forest (20 SU) and Pluviseasonal Dry Forest (20 SU). Subsequent analyses facilitated the estimation of the approximate number of plots to be inventoried in each stratum.

Stratified random sampling was defined as the sampling scheme in which the population was divided into strata and where a simple random sample of *n*th size within each *h*th stratum was selected (Balzarini et al. 2008). A maximum sampling error of 10 % (IPCC 1997) was deemed acceptable for the NFI.

NFI SU were clusters of temporary plots where each one consisted of three subplots arranged in an L-shape, with an area measuring 60 × 60 m and 60 × 40 m depending on the strata (Fig. 18.1). Nested plots were established

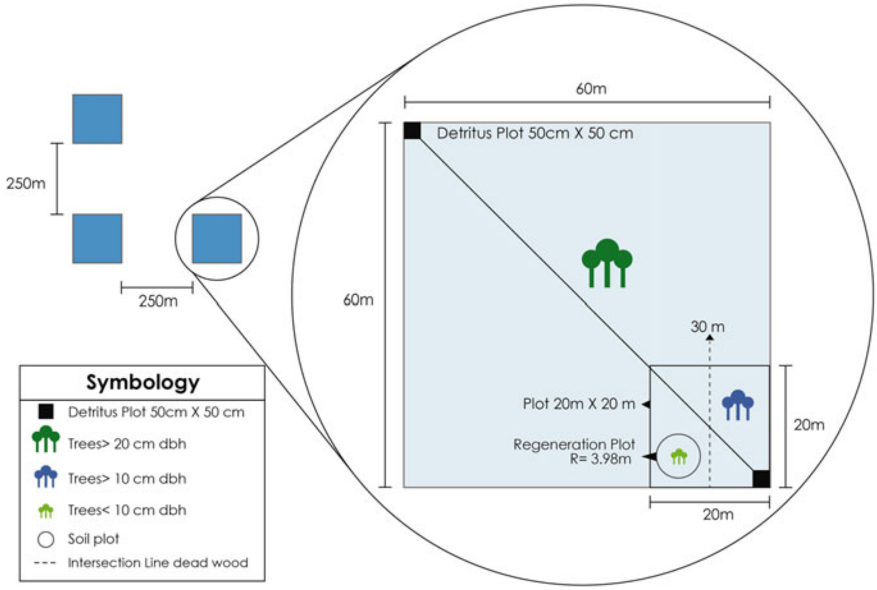

Fig. 18.1 NFI sampling and plot design

within the subplots to measure and capture information from three of the five carbon pools recommended by the IPCC (1997): litter, dead wood, soil and understory. Seven of the strata used square plots (Fig. 18.1) and the Mangrove and Morete Palms strata used rectangular plots.

18.1.3 Data Collection

In the field, precision instruments were used to take measurements. For full details refer to the NFI Field Manuals (MAE 2012). The variables measured in the NFI were:

- Dead wood: Downed wood with diameter ≥10 cm
- Litter and non-living detritus: Organic matter fallen on soil, less than 10 cm and more than 2 mm in diameter
- Soil sample: Color, texture, structure, stoniness, carbon content, bulk density, organic horizon depth
- Living biomass: Living biomass <5 cm dbh. Understory in plantations; shrubs and fruit trees; herbs, crops and cultivated and natural pastures; destructively sampled in the 2 × 2 m plot
- Tree measurements: Living trees, standing dead trees, and stumps. Location, tree species, diameter at breast height (dbh) for trees ≥10 cm dbh in all forest types and ≥5 cm in the Andean High Mountain Evergreen Forest stratum, total height (HT), commercial height (HC), plant health, crown cover, phenology, ethnobotanical uses, and stump decomposition state.

18.1.3.1 Field Work and Quality Control

The information gathering began with the formation of tasks teams for field work. Prior to entering the field, interviews were carried out with key informants such as MAE regional staff, parish leaders, community leaders, indigenous territory leaders, farm owners and local contacts. Support from local contacts helped arrange field access, and necessary permits were managed with the owners of the places where the plots would be established.

The quality of information obtained both in the field and office was monitored and controlled. Quality control took place during field data acquisition after field data collection the data was cleaned prior to the processing and analysis.

In the field, each field team was evaluated by a supervisory sub-team composed of a MAE-FAO technician, a dendrologist, a consultant responsible for the field brigade, and local guides who accompanied the team during data collection.

The sample size for field supervision was determined when the consultant team ended the field work, and consisted of 10 % of the established plots. All information collected in the 10 NFI forms was verified. Qualification criteria was defined to verify the quality of the data collected, representing the different scenarios considered in the methodology, as well as those found at the time the information was collected in clusters.

Further reviews were undertaken in the office by a supervision matrix to correct data such as typing errors. The information generated by the NFI was stored in a database created in the Open Foris Collect software (MAE 2013a). The supervisory process the NFI used is explained in more detail in the Manual of Supervision and Quality Control carried out by MAE-FAO (2014).

Corrections were carried out by numerical logical validators, geographic data verification and the standardisation of criteria such as the correction of inconsistencies of categorical variables registered for each individual. Measurement data was checked to identify out of range values. These values were identified with graphic techniques such as scatter plots of dbh and total height; and outliers were identified through variable standardizing, identifying those values that exceeded the 3.5 standard deviation from the overall mean. The debugged databases were examined with the OFC system and the professional version of the Infostat program (Balzarini et al. 2008).

18.1.4 Data Processing, Reporting and Use of Results

The biomass of standing living trees was calculated in different ways to compare the final results and choose the method that best fits the national needs. The volumetric method used a specific density for each species, an average for genus, average for families, and a weighted average for all other unidentified individuals. Volumetric calculations were also used to categorise the plots as harvestable or non-harvestable, according to the provisions of the three forest regulations of Ecuador.

Furthermore, stratum-specific allometric equations were assigned according to the classification of forests by Chave et al. (2005). The allometric equations selected fit the climatic characteristics of each stratum in the NFA.

With these equations, the amount of carbon in the biomass of living trees with a dbh >10 cm was calculated. First, the dry biomass of each individual tree registered on the plots was estimated using allometric equations. The sum of the biomass of all individuals in each plot was calculated to provide plot biomass estimates. Subsequently, the average biomass per cluster was calculated, and then the mean of the biomass per forest strata. Selected equations required dbh (in cm) and specific wood density (ρ in g/cm^3) as variables. Specific wood density was obtained from FAO's global database of wood densities (Zanne et al. 2009). For calculating root biomass, the value of aerial biomass obtained using the Chave et al. (2005) allometric equations was multiplied by a factor of 0.24 for tropical forest (Cairns et al. 1997).

The NFI results constitute a primary source of information for MAE in the context of forest management and related natural resources. Among the multiple applications given to the NFI outputs, the Ecuadorian report through MAE to the United Nations Framework Convention on Climate Change stands out, as well as the country's Forest Reference Emission Level for Deforestation (FREL) in the context of results-based payments for the REDD+ mechanism, and Ecuador's updating of its forests information for the Global Forest Resources Assessment 2015.

On the other hand in the national context the NFI results have promoted adjustments to the Forest Regulation to improve its management. Various programs and projects of the Ministry of Environment as well as external institutional stakeholders have used this information to strengthen their technical documentation, planning and decisions.

The NFI has generated extensive research among the academia; undergrad, postgrad and doctoral students, as well as forest researchers in the country and the region have shown interest to derive more detailed data and with a higher scientific level.

The possibility of using NFI results in future cycles of measurement, linked with the National Forest Monitoring System of Ecuador, are very broad and ambitious. With certainty, its periodicity will make more information available and will clarify any existing doubts that preliminary results generated.

18.2 Land Use Classification

18.2.1 Classification of Lands and Forests

The National Forest Inventory (NFI) classified land use and forest types based on the criteria required by the Intergovernmental Panel on Climate Change (IPCC). The classification system represents cover and type of land use to estimate carbon stocks and emissions associated with human activities, and uses defined criteria and descriptions of each type of use (IPCC 2006). This classification is based on four characteristics described below:

- Hierarchical: the national forest area is divided into separate scales, defined according to the following criteria:
  - Level 1, IPCC global classification classes
  - Level 2, classification of forest land by biogeographic and physiographic criteria, and for crops according to temporality
  - Level 3, classes according to forest strata with different carbon stock
  - Level 4, classes according to forest exploitation/management (productive/nonproductive).
- Independent: classes are independent of the meanings used according to data collection resources, i.e. satellite images, aerial photos, field data or combinations.

Table 18.1 Area of native Ecuadorian forests strata considered in the NFI

Forest type strata	Area (1000 ha)	Area (%[a])
1-Dry andean forest	174.913	1
2-Pluviseasonal dry forest	720.298	4
3-Andean montane evergreen forest	2030.671	17
4-Andean foothills evergreen forest	533.558	10
5-Andean high mountain evergreen forest	1302.435	4
6-Amazon lowland evergreen forest	6756.679	55
7-Choco lowland evergreen forest	936.978	4
8-Mangrove	151.377	1
9-Morete palms forest	431.458	4
Total forest area	13,038.367	100

[a]The values correspond to percentage area relative to the total area of native forests in Ecuador (MAE 2016c)

- Categorical: classes must be clearly defined; possible errors due to data recording must be identified.
- Flexible: can be used in combination with auxiliary information to form new classes that allow grouping of specific levels of another classification (e.g. FAO Forest Resources Assessment).

Although IPCC guidelines suggest dividing the country into managed and unmanaged areas, Ecuador decided the total land area would be considered as managed.

Using pilot sampling, the historic maps of deforestation for 1990, 2000, and 2008; and preliminary results of the vegetation map of Ecuador, the stratification of native forests was performed based on the methodology for identifying threatened ecosystems in South America (Jarvis et al. 2010). The NFI defined nine strata in which the forests of Ecuador (Table 18.1) were divided to meet IPCC level III. These strata were defined on the basis of the area occupied by these units and the internal variation of biomass and carbon content (MAE 2012).

18.2.2 Characteristics and Conditions of Ecuador's Native Forests

The Republic of Ecuador has an area of 24,898,396 ha (Senplades 2010). The total native forest area in 2008 was 13,038.367 ha. In the 1990s and 2000s several national and international sources identified Ecuador amongst the countries with highest deforestation rates in Latin America. Nowadays the native forest has 12,753.387 ha that represents the 51 % of the continental area of the country (Fig. 18.2). The rate of native forest loss has been reduced to half: from 93,000 ha per year in the 1990s (approximately) to 47,000 ha per year in between 2008 and

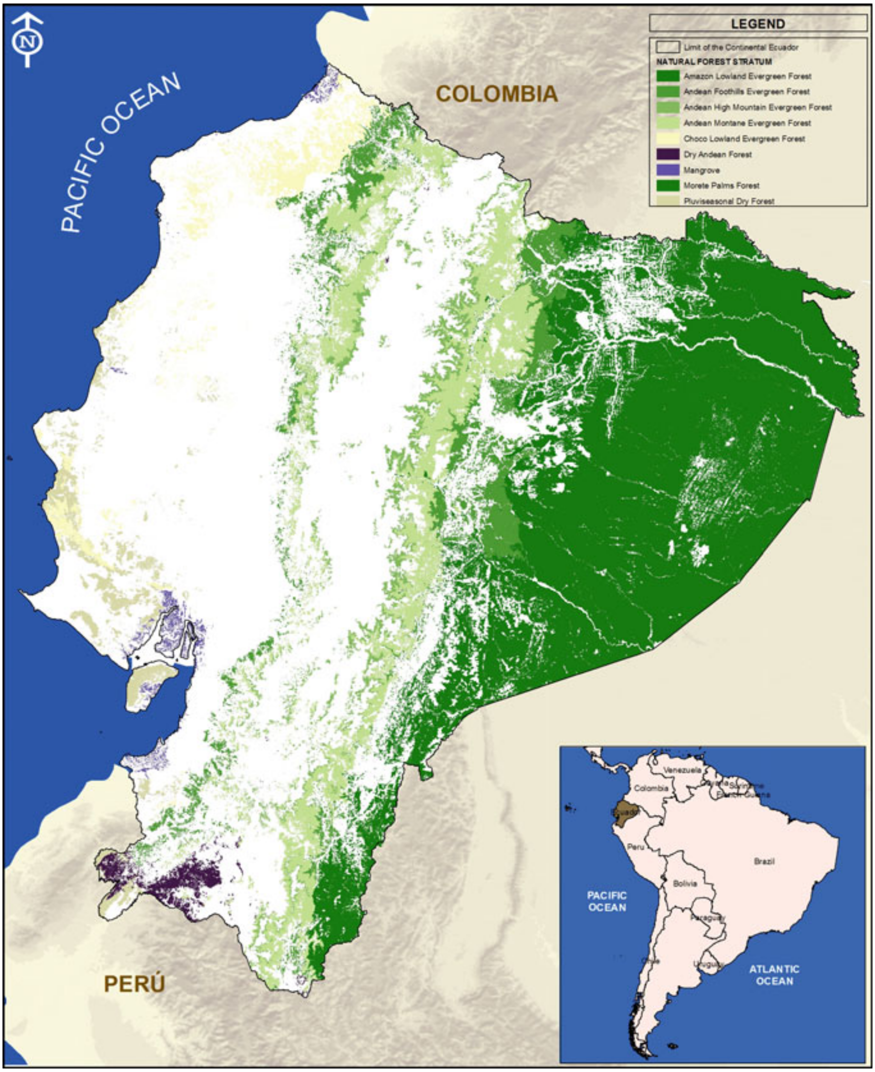

Fig. 18.2 Ecuador's native forest stratum (MAE 2015)

2014 (MAE 2015). This was achieved with sustained efforts by the government and the civil society using initiatives such as the NFA itself, and others programs like Socio Bosque, Forest Control and Wood Traceability System currently in construction (FAO 2015).

MAE's Historic Deforestation Map project updated the land use/land cover map for the continental Ecuador to 2014. In this project the forest was defined as a plant community of at least 1 ha, with trees 5 m in height and a minimum canopy cover of 30 %. This definition differs from FAO's in the inclusion of bamboo and palm-covered areas and the exclusion of agricultural production systems and trees growing in parks and urban gardens. The report shows that the total forest cover area is approximately 50 % of the total land area, equivalent to 13,038,367 ha. The majority of this is Amazonian lowland evergreen forest (MAE 2016a, in press).

The main change in land use in the country is from native forests to agricultural areas, including the establishment of palm oil plantations, especially in the province of Esmeraldas (MAE 2016a, in press). Most of these forests (6.8 million ha), located mostly in the Amazon region in northwestern Ecuador (Bertzky et al. 2011), are in the possession of indigenous peoples and nationalities, the Afro-Ecuadorian people and the State. Private owners (farmers, settlers and processors or loggers) have a relatively small area of natural forest (Añazco et al. 2010). Likewise, most of the forest plantations belong to private owners.

The Map of Ecosystems of the Continental Ecuador (MAE 2013b) recorded 91 ecosystems in the Ecuadorian mainland, reflecting the large floristic diversity of the country (Senplades 2013). Of those ecosystems, 65 are forests, 11 shrubby and 15 herbaceous ecosystems (MAE 2013b). Up to 31 % of Ecuador's total area is under conservation (Patrimony of State Natural Areas (PANE) and the Socio Bosque Program); from this percentage, 87 % is under forest cover, 12 % corresponds to heath and 1 % to shrub and herbaceous vegetation (MAE 2013b).

Ecuadorian laws dictate rules for the use of timber resources of natural wet, Andean and dry forests; cultivated forests: forest plantations, planted trees, trees of natural regeneration in crops; pioneer formations; trees in agroforestry systems; and non-timber forest products (MAE Ministerial Agreement 039 and 040).

Ecuador is a signatory to the United Nations Framework Convention on Climate Change (UNFCCC) and participates in the creation of international policies on climate change, which also guide national mitigation policy development. The forest sector is also involved in the Reducing Emissions from Deforestation and Forest Degradation (REDD+) process through initiatives at the national level. In this process, the NFA is an important contributor to building the system for measuring, reporting and verification (MRV) of mitigation measures to climate change, especially in the context of REDD+ strategies.

18.2.3 Carbon Stock and Its Relation with Forest Tree Structure

A total of 102,647 individual trees were measured in the forest inventory, corresponding to 1639 plots and 711 clusters. Living trees accounted for more than 92 % of the total, whereas the percentages of stumps and dead trees without leaves were almost insignificant (Table 18.2). The stratum with largest sample effort is the Amazon Lowland Evergreen Forest with 174 clusters.

Total above and belowground carbon storage within living and dead biomass above and below ground in Ecuador averages between 37.04 MgC/ha in Andean

Table 18.2 Distribution of individual trees recorded in the forest inventory, according to their status

Tree status	Number of individuals	Individuals (%)
Living	94,773	92.32
Stump	282	0.27
Dead without leaves	744	0.72
Dead without branches	6848	6.67

Dry Forests, to 160.40 MgC/ha in Amazon Lowland Evergreen Forests (excluding soil organic carbon). Andean forests in humid and very humid areas range from 105 to 123 MgC/ha, while other forests in very humid areas range between 76 and 87 MgC/ha. Chave et al. (2005) suggested that bioclimatic classification may not be useful in Ecuador to evaluate variations in carbon at the national scale (Table 18.3).

As expected, living trees accumulate the majority of the carbon (more than 57 %), while the dead biomass and the root biomass are the second most important component in terms of carbon reservoirs, followed by the understory and detritus biomass (Table 18.3). Several reviews (Nogueira et al. 2008; Cummings et al. 2002; Nascimento and Laurance 2002; Russel 1983) show similar proportions for Amazonian forests outside of Ecuador.

The total above ground biomass could actually be higher than the values being reported for Ecuador because lianas and vines were not measured by the NFI. Tropical forest studies suggest that the carbon storage in this component could represent 4.5 % of the total carbon in a forest (Putz 1983).

In terms of tree size, the 10–60 dbh diameter class represents more than 90 % of the total trees, and stores approximately 74 % of the living biomass. Trees with dbh ≥ 60 cm represented less than 5 % of the total trees, suggesting very large trees are a rare occurrence in these forest, and thus showing that carbon stock in the diametric class of trees with dbh ≥ 60 cm is low (Table 18.4).

A strong correlation between tree biomass and tree diameter of dbh ≥ 10 cm ($R^2 = 0.88$, $p < 0.0001$) was found, but the relationship is weak in the case of tree biomass and height (MAE 2016b, in press). It is known that basal area is a good predictor of the carbon biomass in trees, according to reports of primary forests in Australia, Mexico, and Brazil (Cummings et al. 2002; Nightingale et al. 2008; Torres and Lovett 2013), and isolated trees in pasture lands and secondary forests in Costa Rica (Chacón and Harvey 2013; Cifuentes 2008).

The fact that there is a weak relation between tree biomass and tree height should be researched in the future, because studies have demonstrated that, at least for Andean forests, the biomass of trees tends to decrease with elevation (Leuschner et al. 2013; Girardin et al. 2013; Moser et al. 2011). Challenges in accurately measuring tree height in the field may be precluding our ability to find a similar relationship.

Table 18.3 Carbon stock (Ton/ha) in biomass in the 9 forest type strata and by pool

Forest type	Forest type according to Ecuadorian NFA	Living trees	Under-story	Palms	Dead trees with branches (without leaves)	Dead trees (without branches and leaves)	Stump	Fallen wood	Detritus (leaf litter)	Root, living trees	Root, dead tree, stumps	Total (Mg C/ha)
Dry	Andean dry	28.80	1.59	0.00	0.22	0.35	0.01	5.55	4.22	6.91	0.26	47.91
Dry	Pluviseasonal dry (BSP)	25.00	1.49	0.00	0.08	0.32	0.01	2.07	1.86	6.00	0.21	37.04
Humid	Andean montane evergreen (BSVAM)	80.89	4.06	0.10	0.68	5.10	0.02	7.67	2.42	19.41	2.76	123.10
Very humid	Andean foothills evergreen (BSVAPM)	72.94	3.24	0.01	0.54	3.66	0.01	20.73	2.16	17.51	1.97	122.77
Humid	Andean high mountain evergreen (BSVCA)	61.22	7.62	0.07	0.46	3.56	0.01	12.88	2.69	14.69	1.90	105.10
Humid	Amazon lowland evergreen (BSVTBA)	108.12	3.24	0.49	0.39	3.79	0.02	13.32	3.07	25.95	2.02	160.40
Very humid	Choco lowland evegreen (BSVTB)	52.41	3.02	0.05	0.39	1.77	0.12	9.36	2.32	12.58	1.32	83.34
Mangrove	Mangrove (M)	50.12	19.18	0.00	0.23	0.70	0.00	3.96		12.03	0.41	86.63
Very humid	Morete palms (Mo)	49.44	1.16	1.42	0.15	1.01	0.08	6.62	3.47	11.87	0.59	75.80

Table 18.4 Percentage of trees and carbon biomass according to the diametric classes present in the nine strata analysed

Forest type	dbh 10–59.9				dbh ≥ 60			
	Trees		Carbon		Trees		Carbon	
	Number/ha	%	Ton/ha	%	#/ha	%	Ton/ha	%
Andean dry	305	99.2	24.46	84.9	3	0.8	4.34	15.1
Pluviseasonal dry	213	98.6	19.475	77.9	2	1.4	5.52	22.1
Andean montane evergreen	341	98.3	62.585	77.4	6	1.7	18.30	22.6
Andean foothills evergreen	433	98.2	55.495	76.1	8	1.8	17.45	23.9
Andean high mountain evergreen	166	97.6	48.225	78.8	4	2.4	13.00	21.2
Amazon lowland evergreen	415	98.0	79.76	73.8	9	2.0	28.37	26.2
Choco lowland evergreen	319	98.2	39.315	75.0	6	1.8	13.10	25.0
Mangrove	298	99.7	47.675	95.1	1	0.4	2.44	4.9
Morete palms	166	94.6	29.58	59.8	9	5.4	19.87	40.2

18.2.4 Forest Management and Harvesting Systems

Ecuador's Forest Law established forestry regulations that determine administrative and technical aspects regarding the use of timber and non-timber forest products, to ensure the permanency of forest goods and services for medium and long term (MAE 2010).

The Constitution of the Republic of Ecuador states that the Central Government holds the exclusive competence over the forests resources. As a result, the management of forest resources in Ecuador is the responsibility of the MAE. Thus, it authorises timber harvesting upon submission through the approval of formal plans and programs (Table 18.5). These plans are elaborated and carried out almost always by a Forest Engineer, supported by MAE.

In December 2009, MAE detailed the administrative procedures for authorising the sustainable exploitation of timber resources that may originate in: (1) natural forests (Humid, Andean, Dry), (2) planted forests, (3) agroforestry systems (planted trees and natural trees regenerated inside crops), and (4) secondary forests. For non-timber products, harvest plans and programs should be approved according to each case (MAE 2010). Wood products derived from such exploitation (logs, planks, boards, laths and others) are the exclusive property of the owner or

Table 18.5 Classification of forest harvesting and cutting programs by forest type

Natural forests	Forest plantations	Agroforestry systems	Pioneer forests
PAFSu: sustainable Forest harvesting program PAFSi: simplified forest harvesting program PCZCL: cutting program in zones of legal conversion	PCPF: cutting program for forest plantations PCAP: cutting program for planted trees	PCRNC: cutting program for naturally regenerated trees PCAR: cutting program for relict trees	PCFP: cutting program for pioneer forests Cutting forms for pigue (*Piptocoma discolor*) Cutting forms for balsa (*Ochroma pyramidale*)

possessor of the forest, who can market or trade them as he or she sees fit (Orozco et al. 2014).

The NFI is a key tool that has to be applied in the future, with periodically updated data, and new measurement cycles. It should also be included in a complete forest monitoring system. This will enable changes in forest policy to be evaluated. While the NFI establishes the baseline information on timber resources, it also further describes the characteristics of this resource. For forest management and harvest, for example, it is necessary to have data regarding survival, growth and recruitment. Without this information it is difficult to make conclusions about harvest volumes in continuous cutting cycles. In addition, we have to take into account the high biodiversity of forests in Ecuador and the political, economic and social scenarios.

It is very important to consider biodiversity in the management of forests resources, and there are regulations to ensure its protection. Currently, these regulations are being reviewed, to integrate them with the principles of sustainable forest management. The generation of applied forestry research and the strengthening of capacities for monitoring forest management are important technical inputs needed to generate the national forestry regulations and to improve the NFI.

In recent years, Ecuador has made significant efforts to develop policies and strategies to enhance forest governance. These efforts include incentives to reduce deforestation, control forest harvest levels and mobilisation of wood products, and disseminate information about forest regulations. Also, funding has been provided to preserve forests, promote re-vegetation and regeneration of degraded lands, increase reforestation with commercial objectives, and provide resources for training and investigation (Orozco et al. 2014). Particularly, it is important to recognise the efforts made to simplify forestry regulations, as well as launch a verification system for forest legality associated with the Forest Law, containing different controls for all phases of the wood value chain.

There are still unresolved challenges to ensure sustainable forest management (SFM), which are linked to reduced institutional, politic and scientific gaps in forest planning. Also, it is necessary to adapt the forestry regulations to meet the needs of small land owners and native people, who represent a large section of users of exploitable forest resources in the country (Mejia and Pacheco 2013).

The land zonification of the Ecuadorian forests is the key to SFM. The identification of forest areas in production, protection or recovery zones, as well as the defining of priority zones, will allow for sustainable land and forest use planning (MAE and ITTO 2011). In this context, future efforts of the NFI will be guided towards generating inputs of technical information to support this process.

Currently, Ecuadorian Forestry Regulations consider three types of forests: Dry, Humid and Andean. However, data from the NFI show the 9 forest strata that represent more effectively the national forest biodiversity. More efficient monitoring activities and effective policy decisions is recommended, to achieve an adjustment of regulations with a forest stratification made to ensure synchrony between forest units and policies.

For the new NFI cycle, the sample size has to be calculated not only taking into account the size of the strata or the precision level for carbon estimation, but the required precision for important parameters of forestry management and conservation like, i.e. forest productivity, density and structure, recruiting and growth, species diversity, ecosystem services, forest degradation, disturbance and forest dynamics, trees outside forests, non-timber forest products, wildlife, others.

18.2.5 Availability of Forest Resources

Forest resources can be classified into commercial and non-commercial volume. The commercial volume is the volume of the species contained in the national forestry regulations, as well as the volume of species that are not contained in the regulations but with individuals with a diameter greater than the minimum cutting diameter. The non-commercial volume is the volume of all species contained in the regulations. Those individuals with a diameter below the minimum cutting diameter in those areas that are not included in the regulations.

The highest total commercial volume per hectare is found in the Amazon Lowland Evergreen and Andean Foothills strata, while the lowest is found in the Dry Forest, Andean Dry forest and Andean High Mountain Evergreen strata. The Mangrove stratum is the exception, demonstrating a commercial volume lower than 7 m^3/ha (Table 18.6). The Morete Palms stratum has the highest total volume (commercial and non-commercial); however most of it cannot be considered commercial. Most likely, the high volume value is explained by the dominance of the *Mauritia flexuosa* palm, which in this stratum is mixed with other species, and has a high density and large diameters and heights.

In addition, the commercial volume of species considered as prioritised for each stratum was calculated, taking into account the minimum cutting diameter, as indicated in the forestry regulations (Table 18.7).

In most of the strata, the priority species show volumes higher than 50 % of the commercial volume above the minimum cutting diameter. This result shows that these species are susceptible to a considerable reduction of commercial volume in

Table 18.6 Commercial and non-commercial volume per hectare

Strata	Commercial (m^3/ha)	Non commercial (m^3/ha)	Total (m^3)	Commercial (%)
1-Dry andean forest	39.3	21.6	60.9	64.6
2-Pluviseasonal dry forest	37.8	15.8	53.6	70.6
3-Andean montane evergreen forest	56.2	68.2	124.5	45.2
4-Andean foothills evergreen forest	70.5	134.0	204.5	34.5
5-Andean high mountain evergreen forest	31.2	33.4	64.6	48.3
6-Amazon lowland evergreen forest	70.9	167.9	238.8	29.7
7-Choco lowland evergreen forest	47.7	97.9	145.6	32.7
8-Mangrove	6.8	129.3	136.1	5.0
9-Morete palms forest	71.6	215.1	286.7	25.0

Table 18.7 Commercial volume per strata in each identified category according to forest law

Strata	NE (m^3/ha)	ND (m^3/ha)	NE (Percentage of non specified total)	ED (m^3/ha)	ED (m^3/ha)	EE (Percentage of specified total)
1-Dry andean forest	10.3	8.6	54.5	29.1	13.0	69.1
2-Pluviseasonal dry forest	9.1	3.0	75.2	28.8	12.8	69.2
3-Andean montane evergreen forest	37.0	51.7	41.7	19.3	16.5	53.9
4-Andean foothills evergreen forest	44.8	104.7	30.0	25.7	29.3	46.7
5-Andean high mountain	16.5	22.0	42.9	14.6	11.4	56.2
6-Amazon lowland evergreen forest	34.6	134.7	20.4	36.3	33.2	52.2
7-Choco lowland evergreen forest	28.0	79.7	26.0	19.6	18.3	51.7
8-Mangrove	6.8	128.7	5.0	0.0	0.7	0.0
9-Morete palms forest	34.3	188.7	15.4	37.3	26.4	58.6

ND Non-specified below minimum cutting diameter, *NE* Non-specified above minimum cutting diameter, *EE* Specified above minimum cutting diameter, *ED* Specified below minimum cutting diameter the first cutting cycle (15 years according the current forestry regulations in the country). Care should be given to not overexploit these species and risk their ecological roles or long-term permanence.

18.3 Assessment of Wood Resources

18.3.1 Regulatory Restrictions to Forest Harvesting

The harvest and commercialisation of the wood extracted from natural and planted forests, public or private, is regulated by Law of Forestry and Conservation of Natural Areas and Wildlife, established in Book III of the Unified Forestry Regime Text of the Secondary Legislation of MAE. The law establishes a permanent and direct participation of the State in all forestry activities in Ecuador. The State, through MAE, is responsible for native forest management, forest control, regulation, promotion, wood supply and, above all, the restoration of forest resources used by the society. The restoration of forest resources is carried out mainly through forest plantations and, to a lesser extent, through the management of harvested native forests (Carrión and Chiu 2011).

There are regulations and technical standards issued for the management and sustainable use of forests and their resources, which are referred to as the Forest Normative. They include basic criteria that determine legal restrictions for SFM related to the development and implementation of integrated management plans and logging programs of native forests, like the sustainability of production, maintenance of forest cover, biodiversity conservation and co-responsibility in the management and reduction of negative environmental and social impacts. For example, for the sustainable harvest in forest areas, the Forest Normative (Ministerial Agreement 0125) determine that the harvesting intensity (the trees that will be cut for production) must not exceed 30 % of the basal area inside the managed unit and the intensity of intervention (promote the growth of some tree species by the cut of others) may not exceed 40 % of the basal area.

Aspects such as maintaining a minimum mandatory reserve of forest species of low abundance, as well as using "conditioned" species should be done by demonstrating high enough abundance. Forest enrichment should be carried out in gaps, and cannot exceed 50 trees/ha of native species. Understory elimination is permitted only in the case of silvicultural treatments. In terms of conserving biodiversity, species of exceptional ecological importance have to be identified and protected in the forests. Species that have an abundance of less than one tree per three hectares cannot be harvested.

The Forest Normative allows for the identification of Permanent Protection Zones (PPZ) that restrict forest harvesting in essential habitats that are indispensable for the survival and maintenance of populations of threatened species of fauna and flora. Also, forest harvesting is restricted on river flows (i) with slopes greater than

50° and a width greater than 3 m (ii) areas with slope greater than 70° and (iii) in areas declared as public interest or in areas declared as protection zones by the owners. The riverbanks, water reservoirs and intermittent water holes are also declared as PPZ.

The forests inside the State Patrimony Natural Areas (PANE in Spanish) and other protective forests are represented by the set of wild lands that stand out for their protective, scientific, scenic, educational, touristic and recreational value; because of their flora or fauna, or because its ecosystems contribute to the environmental equilibrium (Forest Law Art. 69). Due to the protective character of these areas, forest harvesting is not permitted. The area of protection is considered natural capital, from which only the flux of environmental services such as hydric cycle regulation, landscape beauty, biodiversity protection, greenhouse gases mitigation, etc. can be harvested.

Forest resource use is also regulated by accessibility, particularly in remote areas and mainly in the Amazon region where there are high slopes; also, areas of social conflict restrict forestry activities. Finally phenology, flowering, pollination, seed dispersal, germination, light and nutrient requirements, forest regeneration, among others ecological considerations sustain the productivity of the site and can limit the amount of timber resources extracted during harvesting operations.

18.3.2 Evaluation of Timber Resources Available for Harvesting

In Ecuador, there are harvesting zones ("units" or "blocks") that are integrated with the State Forests National Patrimony. These zones were incorporated into the national forest regime, and were delimited provisionally through the Ministry Agreement 202, specifically in the provinces of Esmeraldas and Napo. However, not all the areas that are under the Ecuadorian forest regime are susceptible to harvesting because it is limited to those "units" or "blocks". Outside those areas, harvesting is subject to a process of forest licensing through formal petition of the owner to the governing body (MAE). All the information is stored at the institutional level in a Forest Management System (SAF), which provides volume, surface and geographic data, and contains cartographic and alpha-numerical information that belongs to the information systems in the MAE.

Currently, not all of the forest resources in the country are available for harvest. The country has more than 4000 tree species, but no more than 200 are suitable for use. Also, in most cases, the population of the exploitable species are being reduced. Therefore there is limited information that can be used to determine sustainable harvest levels. This makes relevant develop methodological protocols designed in a way that includes the sustainable forest management considerations currently defined in Ecuadorian forest law.

On the other hand, the NFA value has been limited to a tool to orient and review management decisions about forests and territories in general by the lack of connection between the way regulations are defined, identifying of development priorities, planning processes and the forest stratification. Under this scenery it is necessary to use the prior definition of priority areas in terms of net productivity, growth, quality, recruiting and replacement of the forest reserves (including the connectivity between natural remnant forest masses). This will allow for territorial zoning which incorporates ecological and productive considerations.

18.4 Conclusion

For the new measurement cycle (2016–2019) the primary goal is to consider the lessons learned from the first NFA on an institutional, technical, methodological, logistical and financial level.

The data acquired in the first NFA facilitated information about management priorities in forest strata or political geographic zones. In most cases, the NFA detected identifiers to evaluate the necessity of developing mechanisms to obtain more detailed and precise data. Thus, forest monitoring in a broader perspective and the future of NFA became a key issue policy development, environmental management and the utilisation and conservation of natural resources, at various scales in Ecuador.

Future challenges for the NFA include the characterisation of high diversity zones, monitoring high conservation value areas and the quantification of human activities on biodiversity, through identifying indicators of biodiversity, forestry, hydrology, soil conservation, watershed management, issues of urban/rural planning, environmental services, generating policies, stewardship of related actors and governance scenarios, One particular aspect to be included is the monitoring of trees outside the forests, to enhance approaches to integrated management of landscapes, and including other types of land uses in forest monitoring. More specific issues for the NFA to address include; the strengthening the forest classification system, reducing uncertainties, automating databases and enhancing biomass and carbon calculations using local factors and conditions. The NFA must incorporate into the country's REDD+ Measuring, Monitoring, Reporting and Verification (MRV) system.

An aspect that requires a particular focus on the NFI is the inclusion of trees outside forests, because this represents significant resources that must be quantified for management and sustainable use, e.g. agroforestry and silvopasture systems, also, urban and rural forestry schemes. Today trees outside forests are the subject of extensive debate; thus, the NFI should gradually incorporate it in the analysis, design and technical measurement protocols.

The NFA must be coordinated with parallel initiatives lead by MAE and related to the analysis of land cover/land use and ecosystem identification. Consolidating remote sensing, field campaigns (National Forest Inventory) and other program elements into the first National Forest Monitoring System of Ecuador (NFMSE) should continue to be promoted and pressed for in the political spheres.

In the case of those forest strata that the NFA identified as being very limited in terms of timber production, the new measurement cycle should incorporate variables emphasising ecosystem services. This would support the generation of conservation and sustainable use strategies in those strata.

In the context of mitigation and climate change, and specifically for REDD+, the NFA should provide the necessary information to calculate emission factors, characterise activity data, and support the establishment of reference levels. Together, these data will help quantify current and estimate future forest emissions and to the actual impact of REDD+ actions.

Furthermore, future NFA processes must also contribute to rural development planning in Ecuador. Forest management should be understood as part of the process of building a culture to regularly review strategies for the forest sector and related sectors.

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