Food and Agriculture Organization of the United Nations

NATIONAL FOREST INVENTORIES of LATIN AMERICA and the CARIBBEAN

Towards the harmonization of forest information

CSIC Consejo Superior de Investigaciones Científicas · INIA Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria · ENFIN · UFAM · INFOR

NATIONAL FOREST INVENTORIES of LATIN AMERICA and the CARIBBEAN

Towards the harmonization of forest information

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FOREWORD

High-quality, accessible and transparent forest data is necessary to sustainably manage forests and to track progress towards commonly agreed international goals and targets, such as the Sustainable Development Goals (SDGs) and the nationally determined contributions (NDCs), which aim to achieve the objectives of the Paris Agreement.

With over 60 years of experience in forest monitoring, the Food and Agriculture Organization of the United Nations (FAO) remains committed to these efforts and provides FAO Members with the technical support they need to develop and implement national forest inventories (NFIs). Forest inventories are systematic collections of data in any given country or territory on the size, location, composition, diversity, health, use and other characteristics of forest resources.

One fourth of the world's forests are found in Latin America and the Caribbean (LAC), including the largest tropical forest in the world, found in the Amazon basin. Forests in this region provide important environmental services at both national and global levels and supply wood, food, shelter and livelihoods for millions of people. The vast area and the wide diversity of forest ecosystems that LAC boasts are testament to the important environmental role that the region plays in biodiversity conservation and climate change mitigation.

National Forest Inventories of Latin America and the Caribbean: Towards the harmonization of forest information is the result of a fruitful collaboration between FAO, the Federal University of Amazonas of Brazil, the Forestry Institute of Chile, and the Spanish National Institute for Agriculture and Food Research and Technology of the Spanish National Research Council.

This publication has made been possible thanks to the contributions of specialists from 21 countries in the region who worked jointly to describe their NFIs and to share information about their history, data collection methodologies, definitions and analysis of main variables, future prospects, opportunities and challenges in implementation.

The publication began as an initiative to set up a network of forestry experts in the region, with the aim to share experiences and learn through the process of harmonization of key forest-related variables in LAC. Efforts like this will enhance the comparability and transparency of national and international reporting on key indicators describing the region's forest resources, as well as how they are managed and used.

I encourage you to explore and fully utilise the information presented in this publication.

Happy reading.

Mette L. Wilkie

Director,
Forestry Division,
Food and Agriculture Organization
of the United Nations (FAO)

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Peru

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ABBREVIATIONS AND ACRONYMS

AFE-COHDEFOR	State Forestry Association, Honduran Forestry Development Corporation
AGB	above-ground biomass
ANTEL	National Telecommunications Administration (El Salvador)
BAP	Andean Patagonian Forest (Argentina)
BGB	below-ground biomass
BPI	Biophysical Inventory (Jamaica)
BSA	Andean Dry Forest (Ecuador)
BSP	Pluviseasonal Dry Forest (Ecuador)
BSP	benefit sharing plan
BSTBCH	Chocó Lowlands Evergreen Forest (Ecuador)
BSVAM	Andean Montane Evergreen Forest (Ecuador)
BSVAPM	Andean Evergreen Forest of the foothills (Ecuador)
BSVCA	Andean Evergreen Forest of Ceja Andina (Ecuador)
BSVTBM	Amazon Lowlands Evergreen Forest (Ecuador)
C&I SFM	Criteria and Indicators for Sustainable Forest Management
CATIE	Tropical Agricultural Research and Higher Education Center
CBD	Convention on Biological Diversity
CCAD	Central American Commission for Environment and Development
CIDA	Canadian International Development Agency
CIEFAP	Andean Patagonia Forest Research and Extension Centre
CIRAD	French Centre for International Cooperation in Agricultural Research for Development
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CLIRSEN	Center for Integrated Surveys of Natural Resources by Remote Sensing
CO_2	carbon dioxide
CONABIO	National Commission for the Knowledge and Use of Biodiversity (Mexico)
CONACYT	National Council for Science and Technology (Mexico)
CONAFOR	National Forest Commission (Mexico, Nicaragua)
CONAP	National Council for Protected Areas (Guatemala)
CRESER	Regional Center for Studies and Services
CTFT	Technical Centre for Tropical Forestry (France)
DAB	diameter at the base
DANE	National Administrative Department of Statistics (Colombia)
DBH	diameter at breast height
DGF	General Forestry Directorate (Uruguay)
DIP	Paraná Deltas and Islands (Argentina)
DNB	National Forestry Directorate (Argentina)
DNF	National Forestry Directorate (Ecuador)
DOB	diameter outside bark
DRC	diameter at the root collar
EFR	Experimental Forests and Ranges
EML	Ecological Metadata Language
ENBN	National Native Forest Strategy (Uruguay)
ENFB	National Forest and Biodiversity Assessment (Honduras)
ESP	Espinal (Argentina)

FAIR	findable, accessible, interoperable and reusable
FAM	Food and Agriculture Microdata
FANTEL	Special Fund from Resources from ANTEL's Privatisation (El Salvador)
FAO	Food and Agriculture Organization of the United Nations
FCPF	Forest Carbon Partnership Facility
FIA	Forest Inventory and Analysis (United States of America)
FLEGT	forest law enforcement, governance and trade
FMU	Forest Management Unit (Jamaica)
FMU	Forest Monitoring Unit (Dominican Republic)
FNNFI	First National Native Forest Inventory (Argentina)
FONAFIFO	National Forestry Financing Fund (Costa Rica)
FORMNET-B	Forest Monitoring Network of Belize
FPMP	Forest Planning and Management Project (Belize)
FR	Forest Reserve (Jamaica)
FRA	Global Forest Resources Assessment
FREL	Forest Reference Emission Level
FURB	Regional University Foundation of Blumenau (Brazil)
FYDEP	Petén Economic Development and Promotion Project (Guatemala)
GEF	Global Environment Facility
GHG	greenhouse gas
GHGI	greenhouse gas inventory
GIMBUT	Interinstitutional Monitoring Group on Forests and Land Use (Guatemala)
GIS	Geographical Information System
GIZ	German Corporation for International Cooperation
GPS	global positioning system
IAvH	Alexander von Humboldt Biological Resources Research Institute (Colombia)
IBGE	Brazilian Institute of Geography and Statistics
IBRD	International Bank for Reconstruction and Development
ICF	National Institute of Forest Conservation and Development, Protected Areas and Wildlife (Honduras)
IDEAM	Institute of Hydrology, Meteorology and Environmental Studies (Colombia)
IGN	National Institute of Geographic and Forest Information (France)
IIAP	John von Neumann Environmental Research Institute of the Pacific (Colombia)
INAB	National Forest Institute (Guatemala)
INAFOR	National Forestry Institute (Nicaragua)
INE	National Institute of Ecology (Mexico)
INEGI	National Institute of Statistics and Geography (Mexico)
INFONAC	National Forest Inventory (Honduras)
INFOR	Forestry Institute (Chile)
INFyS	National Forest and Soil Inventory (Mexico)
INIFAP	National Institute of Forestry, Agriculture and Livestock Research (Mexico)
INRENA	National Institute of Natural Resources (Peru)
IPCC	Intergovernmental Panel on Climate Change
ITTO	International Tropical Timber Organization

LAC	Latin America and the Caribbean
LGDFS	General Law on Sustainable Forestry Development (Mexico)
LiDAR	light detection and ranging
LUC	land use class
LULUCF	land use, land use change and forestry
MAATE	Ministry of the Environment, Water and Ecological Transition (Ecuador)
MAG	Ministry of Agriculture and Livestock (El Salvador)
MAP	main assessment plots (Suriname)
MAPA	Ministry of Agriculture, Livestock and Food Supply (Brazil)
MARENA	Ministry of the Environment and Natural Resources (Nicaragua)
MARN	Ministry of the Environment and Natural Resources (Dominican Republic, El Salvador)
MAyDS	Ministry of Environment and Sustainable Development (Argentina)
MCD	minimum cutting diameter
MGAP	Ministry of Livestock, Agriculture and Fisheries (Uruguay)
MiAMBIENTE	Ministry of the Environment (Panama)
MIDAS	Mobile Integrated Data Acquisition System
MINAGRI	Ministry of Agriculture and Irrigation (Peru)
MINAM	Ministry of the Environment (Peru)
Mo	Moretales (Ecuador)
MON	Monte (Argentina)
MOSEF	Modernization of the Honduran Forestry Sector
MRV	measurement, reporting and verification
NDC	nationally determined contribution
NFA	national forest assessment
NFCI	National Forest and Carbon Inventory (Panama)
NFDP	National Forest Development Plan
NFE	National Forest Estate
NFI	national forest inventory
NFIS	National Forest Information System
NFMA	National Forest Monitoring and Assessment
NFMS	National Forest Monitoring System
NFWI	National Forest and Wildlife Inventory (Peru)
NGHGI	national greenhouse gas inventory
NGO	non-governmental organization
NIMS	National Information Management System
NNFI	National Native Forest Inventory (Argentina)
NP	nested plot
OFC	Open Foris Collect
OLI	Operational Land Imager
ONF	National Forests Office (France)
PCH	Chaqueño Park (Argentina)
PDR	portable data recorder

PNOT	National Land Management Plan
PSP	potential sampling point (Argentina)
PSP	principal sample plot (Suriname)
PSU	primary sampling unit (Dominican Republic, Mexico)
PSU	permanent sampling unit (Bahamas)
QA	quality assurance
QC	quality control
REDD+	Reducing Emissions from Deforestation and Forest Degradation
RU	record unit (Peru)
SACC	Quality Assurance and Quality Control System (Mexico)
SDG	Sustainable Development Goal
SEMARNAT	Ministry of the Environment and Natural Resources (Mexico)
SEN	National Statistical System (Colombia)
SERFOR	National Forest and Wildlife Service (Peru)
SFB	Brazilian Forest Service
SIMOCUTE	National Land Use, Land Cover and Ecosystems Monitoring System (Costa Rica)
SINA	National Environmental System (Colombia)
SINAC	National System of Conservation Areas (Costa Rica)
SMByC	Forest and Carbon Monitoring System (Colombia)
SNIF	National Forest Information System (Mexico)
SNNFI	Second National Native Forest Inventory (Argentina)
SP	sampling point (Argentina)
SPA	Paranaense Forest (Argentina)
SPF	forest subplot (Colombia)
SRS	Southern Research Station (United States of America)
SSU	secondary sampling unit
SU	sampling unit
SySINF	National Forest Inventory System (Nicaragua)
TU	Technical Unit
UMAFOR	Forest Management Unit (Mexico)
UNALM	Universidad Nacional Agraria La Molina
UNCCD	United Nations Convention to Combat Desertification
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
UN-REDD	United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries
USDA	United States Department of Agriculture
UVG	Universidad del Valle de Guatemala
VGNFM	Voluntary Guidelines on National Forest Monitoring
WMU	Watershed Management Unit
YUN	Yungas (Argentina)

EXECUTIVE SUMMARY

National forest inventories (NFIs) provide robust and useful data for sustainable forest management and climate action. As one of the major components of all National Forest Monitoring Systems (NFMS), NFIs build upon multiple data sources, including field inventories, remote sensing and socioeconomic surveys, to estimate relevant forest characteristics at particular points in time.

National forest inventories generate information that has a positive impact on society, as they provide scientifically based data for the development of national and international policies related to forests, as well as for public and private forest planning and management.

The need for reliable, transparent and comparable information has taken on special relevance given country commitments to track and report progress under various international frameworks, including the Sustainable Development Goals (SDGs) of the 2030 Agenda, the Paris Agreement, the commitments in support of the United Nations Decade on Ecosystem Restoration and the targets of the post-2020 Global Biodiversity Framework. Accurate and timely information on forest resources and their changes is also needed to verify country progress under the Reducing Emissions from Deforestation and Forest Degradation (REDD+) mechanism.

Committed to achieving these targets, providing better forest information and guiding better decisions, 21 Latin American and Caribbean (LAC) countries joined forces to develop this publication, with the aim of compiling, comparing and harmonizing their NFI methodologies. These efforts were consolidated after four expert meetings were held to share experiences on NFIs between 2012 and 2018.

The introduction of this book describes the background of the initiative; the relevance and history of NFIs in the LAC region; previous experiences in the harmonization of forestry information in other regions; building the network of experts and collaborators of the LAC NFIs; and the benefits of NFI harmonization.

Four regional analyses were developed to gain a deeper understanding of the similarities and differences of NFI designs, the future prospects, the challenges and opportunities, and to justify transparent and open NFI data.

The designs of the LAC NFIs were shaped by different objectives, according to the particular needs and circumstances of each of the countries. Due to the unique nature of each NFI, data collection standards cannot be established. However, future efforts will strengthen the harmonization of NFIs in LAC; for example, by harmonizing target variables prioritised by the participating countries.

The NFIs of most LAC countries are continuous processes with well-established permanent field inventories. A majority of NFIs were designed and built with a long-term vision to improve knowledge about forests and to facilitate planning, decision-making and policy evaluation on a periodic basis.

Of the region's almost 70 000 established sampling units, 95 percent are permanent. These represent a continuous data source for national estimates of forest volume and biomass; tree growth and mortality; emissions and removal of greenhouse gases of forest-related activities; composition of primary and secondary forests; biodiversity; natural and anthropogenic disturbances in forests; and the use, management and state of timber products and non-timber products by local communities, among other variables.

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The future prospects, challenges and opportunities of the LAC NFIs were analysed based on separate surveys carried out with national focal points. Despite the progress on institutional arrangements made by countries to facilitate the permanence of NFIs, the most evident challenge is long-term financial stability, an issue that requires further discussion as it is necessary to define mechanisms and sources of financing that ensure sustainability.

The advantages of opening NFI data for widespread use were also explored, for example, understanding how the combination of comparability and transparency with open data may catalyse collaborative solutions, as these are robust and reliable data for national and international reporting. These actions will also encourage both public and private investment in projects that lead to the sustainable development of the forestry sector in LAC countries.

This book is a milestone that marks the beginning of the harmonization process of NFIs in LAC. Its aim is to analyse operational reference definitions for the most important NFI variables based on the Global Forest Resources Assessment definitions. Thus, it will serve to develop harmonized regional estimates and contribute to improved national definitions and estimates, replicating the successful example of the European National Forest Inventory Network (ENFIN), which enabled the production of truly comparable estimates of key variables (for example, volume and biomass). For LAC countries, the recommendations from the harmonization process will be essential to improve estimates, especially for the greenhouse gas inventories and payments of REDD+ results. It will also help to improve the national reports of LAC countries to the Global Forest Resources Assessment and other international requirements.

The experience gained from evaluating forest inventories of LAC has direct implications for decision-makers. It shows that the information generated is applicable for various purposes and highlights the relevance of ensuring the continuity of NFIs as a basic strategy for long-term monitoring of natural resources. In a transversal way, NFIs provide information that accompanies all commitments and opportunities in the sustainable management of forests in the 21st century.

NATIONAL FOREST INVENTORIES OF LATIN AMERICA AND THE CARIBBEAN

Towards the harmonization of forest information

PART 1

1 INTRODUCTION

2 SIMILARITIES AND DIFFERENCES IN THE DESIGN OF NATIONAL FOREST INVENTORIES IN LATIN AMERICA AND THE CARIBBEAN

3 FUTURE PROSPECTS FOR NATIONAL FOREST INVENTORIES IN LATIN AMERICA AND THE CARIBBEAN

4 CHALLENGES AND OPPORTUNITIES FOR NATIONAL FOREST INVENTORIES

5 TOWARDS TRANSPARENT AND OPEN DATA IN NATIONAL FOREST INVENTORIES

Chapter

INTRODUCTION

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1.1 UNITED TO IMPROVE FORESTRY INFORMATION

National forest inventories (NFIs) are processes for the measurement, collection and analysis of field data, combined with remote sensing, generally conducted by governments in order to produce statistics on the status, distribution and trends of a country's forest resources for science-based decision-making on planning, implementation and reporting of national and international policy outcomes (see Guatemala and Mexico national chapters; FAO, 2017; Freitas *et al.*, 2010; ICONA, 1990; INAB and CONAP, 2020; MAATE, 2021; Tomppo *et al.*, 2010). National forest inventories are a key component of National Forest Monitoring Systems (NFMS), which provide multiple variables for monitoring changes and trends in forests and trees (FAO, 2017). National Forest Monitoring Systems are a comprehensive group of people, institutions, resources and processes which collect, analyse, assess, interpret and report data for monitoring trends in forest resources over time (FAO, 2017; FAO, 2018a; Ramírez and Morales, 2021).

Due to the technical and scientific challenges in designing, implementing, disseminating and maintaining updated NFI information in Latin America and the Caribbean (LAC), a series of meetings was organized to learn about progress and share experiences among countries in the region. The first meeting was held in Valdivia, Chile in 2012 to discuss the objectives of NFIs and their different statistical designs. Representatives from Argentina, Bolivia (Plurinational State of), Brazil, Chile, Ecuador, Panama, Paraguay, Peru, United States of America, Uruguay, Food and Agriculture Organization of the United Nations (FAO) and local authorities attended the meeting. As a result of the discussion, a forest ecosystem monitoring network was proposed, aimed at bringing together different specialists to exchange data and information on national forest inventories; however, the idea did not come to fruition due to a lack of country participation (FAO and INFOR, 2012).

The second meeting was held in Santa Cruz de la Sierra, Bolivia (Plurinational State of) in 2013, at the initiative of the Spanish National Institute for Agricultural and Food Research and Technology of the Spanish National Research Council (INIA, CSIC) and the Spanish Agency for International Development Cooperation (AECID) with the aim of promoting forest monitoring techniques, exchanging knowledge and experiences and addressing the rationale for NFI harmonization. Representatives from Bolivia (Plurinational State of), Chile, Ecuador, Honduras, Paraguay, Peru and Uruguay participated in the meeting and expressed their interest in establishing an NFI network.

The third meeting was held in 2017, organized by the Brazilian Forest Service (SFB), FAO, the Tropical Agricultural Research and Higher Education Centre (CATIE), and the Federal University of Amazonas of Brazil (UFAM), with the collaboration of the International Union of Forest Research Organizations (IUFRO) and the National Forestry Commission of Mexico (CONAFOR). The objective was to share advances

and experiences in the implementation of NFIs in Amazonian and Mesoamerican countries and to continue promoting the creation of a network to facilitate the exchange, comparability and adoption of modern technologies. Participants included Bolivia (Plurinational State of), Brazil, Costa Rica, Ecuador, Guatemala, Honduras, Peru, Suriname, INIA representing the European National Forest Inventory Network (ENFIN), the Amazon Cooperation Treaty Organization (ACTO) and the Mesoamerican Virtual Center of Excellence in Forest Monitoring (CEVMF). This meeting reinforced the need for harmonization to strengthen NFIs, maintain regular communication, develop comparative studies of concepts, terms and definitions, and learn from the experience of other regions such as ENFIN and the North American Forestry Commission (NAFC) (Braun *et al.*, 2017).

The fourth meeting of relevance was held in Turrialba, Costa Rica in 2018, organized by the SFB, CATIE and FAO, with the collaboration of INIA-ENFIN and NAFC. The objectives were to strengthen the community of NFI experts in the region, define objectives and themes for harmonization, establish guidelines for the establishment of the NFI network and define a work plan and future opportunities. Participants included Brazil, Costa Rica, Dominican Republic, El Salvador, Guatemala, Mexico, Peru and Suriname. The conclusions were to include countries from the Southern Cone and the Caribbean; maintain the support from FAO, INIA, CATIE, NAFC, the United States Department of Agriculture Forest Service and ACTO, as well as a work and communication agenda; and develop a book on NFIs in the LAC region (Argüello *et al.*, 2018).

The initiative of the network and development of the NFI book was presented during the Thirty-first Session of the FAO Latin American and Caribbean Forestry Commission (LACFC), where delegates recommended that FAO "revitalize regional networks [...] and strengthen the forest monitoring and inventory network"; and "promote capacity-building for inventory and monitoring of forest plantations and native forests, and facilitate the follow-up of national REDD+ initiatives" (FAO, 2019).

At the Thirty-second Session of the LACFC, four countries recommended FAO to further support the consolidation of the NFI network in the region (FAO, 2021a).

To initiate the activities with the collaboration of INIA, FAO, CATIE and the SFB, a session was convened to address the issues of cooperation and harmonization of NFIs at the XXV IUFRO World Congress, with the participation of Brazil, Chile, Ecuador, ENFIN and NAFC (Alberdi and Chacón, 2019).

This book is the second collaborative activity and represents a voluntary effort of NFI managers from 21 countries, with support from FAO, INIA, UFAM and the Chilean Forestry Institute (INFOR). The objective is to review and organize experiences in the design, planning and implementation of NFIs in LAC and to identify commonalities and differences in definitions and methods for collecting scientific information on forests. This is a South-South cooperation effort originating from the participating countries as a first step towards the harmonization of forest data in LAC, which represents an important step towards comparable, transparent and open data.

1.2 RELEVANCE OF NATIONAL FOREST INVENTORIES FOR LATIN AMERICA AND THE CARIBBEAN

Forest information is necessary to understand and assess the influence of human actions on the environment and climate change and is essential to make the most appropriate decisions on forest management at national, regional and global levels. For Latin America and the Caribbean, this is highly relevant given the region's 940 million hectares of forest, which represents 23 percent of the world's forests and 47 percent of the region's land area (FAO, 2021a).

National forest inventories are relevant because they provide data for multiple forest indicators to monitor national public policies and for international reports, such as the Global Forest Resources Assessment (FRA) (www.fao.org/forest-resources-assessment/en/), the Sustainable Development Goals (SDGs) (www.un.org/sustainabledevelopment/), the nationally determined contributions (NDCs) of the Paris Agreement (www4.unfccc.int/sites/NDCStaging/Pages/Home.aspx), the Reducing Emissions from Deforestation and Forest

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Degradation (REDD+) mechanism (https://redd.unfccc.int/), the criteria and indicators for sustainable forest management of the International Tropical Timber Organization (ITTO) (www.itto.int/sustainable_forest_management/criteria_indicators/), the Aichi Targets of the Convention on Biological Diversity (CBD) (www.cbd.int/sp/implementation/), commitments on restoration of deforested and degraded landscapes such as the Bonn Challenge (www.bonnchallenge.org/) and the Latin American and Caribbean Initiative 20x20 (https://initiative20x20.org/).

On the other hand, international information requirements have established a basis for expanding, developing and strengthening the region's NFIs and, for this reason, there is now data and information with solid scientific foundations, as several authors have noted (Kangas and Maltamo, 2007; McRoberts *et al.*, 2013; Schreuder, Ernest and Ramírez-Maldonado, 2004). As described below, FAO has historically supported LAC countries in developing their NFIs. The most recent was during the 2000s through an initiative targeting tropical countries, as it was identified during the FRA 2000 that the information reported by most countries was not coming from an inventory with a robust design (Saket, 2002).

Thereafter, international support increased due to the need to strengthen capacities for the REDD+ mechanism, which requires information from NFMS, within which NFIs are a key pillar for the collection of field information to estimate greenhouse gas (GHG) emissions and removals from forestry activities (FAO, 2018a; UNFCCC, 2014). National forest inventories provide data to develop forest emission factors, which are estimated from measurements of live trees, dead standing trees, fine and coarse dead wood debris, leaf litter and soil organic carbon.

Emission factors are expressed in tonnes of carbon dioxide equivalent per hectare, which, when multiplied by the area of change under activities such as deforestation, forest degradation or forest restoration, yield a country's forest emissions and removals (IPCC, 2006). National forest inventories also contribute data to improve estimates of areas of change, as they support model calibration and assess the accuracy of maps (GFOI, 2020). In addition, NFIs with repeated measurements also provide data on carbon losses and gains from tree growth and mortality (GFOI, 2020).

National forest inventories in LAC are also a source of data on forest composition and biodiversity. During the measurements, botanical samples are collected for tree species identification in national herbaria. Some countries also include shrubs and herbaceous plants. In the case of the Brazilian NFI, which is still in progress, officials report that there are about 30 possible new species collected by the NFI that are yet to be verified in national herbaria. A relevant result of this NFI was the rediscovery of *Chiococca insularis* ([Ridley] C.M. Taylor & M.R.V. Barbosa), a species that was thought to be extinct for more than 130 years (Figueira *et al.*, 2020).

National strategies for sustainable forest management and restoration in LAC can also use NFI data on area by type of vegetation, biomass stocks or volume of wood, fuelwood and other non-wood forest products, biodiversity and ecosystem services, indicative species of primary and secondary forests, natural and anthropogenic disturbances such as pests, diseases and forest fires, legal status and ownership (see national chapters of Guatemala, Mexico and Peru; Alberdi, 2021; GFOI, 2020).

Finally, as can be read in the national chapters in Part II of this publication, some countries also collect data on socioeconomic and governance aspects of forests through interviews with landowners and communities to link the relationship of forests to people, poverty and food security (see the national chapters of Brazil, Ecuador, Guatemala, Honduras, Nicaragua and Peru), which provide information about the relationship of forests to people, poverty and food security.

1.3 LATIN AMERICA AND THE CARIBBEAN IN THE HISTORY OF NATIONAL FOREST INVENTORIES

The scope of information provided by NFIs is a consequence of the information requirements for the management of products and services provided by forests throughout history. National forest inventories trace their origin to when Norway's forests needed to be surveyed for timber harvesting in 1919 (Landsskogtakseringen, 1920, cited by Breidenbach *et al.*, 2020). Soon after, in the 1920s, NFIs were initiated in Finland and Sweden (Tomppo *et al.*, 2010); and in the 1960s during the reconstruction phase after World War II, NFIs started in Austria, France, Greece, Portugal and Spain (Breidenbach *et al.*, 2021). This was due to the need to control the overutilisation of forests, among other reasons. On the other hand, in the Americas, the United States of America conducted multiple assessments and reports on the status of timber resources starting in the late nineteenth century, and since then, methodologies for collecting data on forests for industrial timber production have been developed and improved (LaBau *et al.*, 2007).

In the LAC region, the first country reporting the need to collect forest information is Colombia with "the enactment of Law 119 of 1919, which ordered the creation of a Forestry Commission whose main mission was to classify and measure the country's forests" (see Chapter 11). However, it was not until 1945 that the first field survey was carried out in Chile to estimate the stock, quality and health of trees; equations and a map based on aerial photographs were also produced (see Chapter 10). Next, in Brazil in the 1950s, a forest inventory was carried out to assess 19 million hectares with the aim of creating wood processing industries (see Chapter 9). Later, between the 1960s and 1970s, inventories followed in areas with greater industrial potential in the Dominican Republic, Ecuador, Guatemala, Honduras, Mexico, Panama, Peru and Suriname, and thus did not cover the entire national territory. Many of these NFIs were promoted by FAO.

Starting in the nineteenth century, principles of sustainable forest management were formulated in Europe (von Carlowitz, 2013), embodying the need to assess biodiversity even before this word was being defined (Chirici, Winter and McRoberts, 2011). This was followed by the initiation of NFIs

in most Central European countries in the 1980s, as well as the collection of data on forest health, as an ecosystems perspective began to emerge (Vidal *et al.*, 2016a).

The need for information on forests continued to grow in the 1990s, following the United Nations Conference on Environment and Development, with the establishment of the international conventions related to climate change (https://unfccc.int/resource/docs/convkp/conveng.pdf), biological diversity (www.cbd.int/doc/legal/cbd-en.pdf) and the statement of principles on forest management (www.un.org/esa/documents/ga/conf151/aconf15126-1.htm). In parallel, FAO continued to develop FRAs and it was for the 2000 report that the Committee on Forestry (COFO) recommended that the approach be expanded to respond to the needs of these international conventions (FAO, 2018b). In addition, based on that assessment, an analysis was conducted on the source of data provided by countries for the development of FRAs. It was demonstrated that most of the data came from expert estimates and only 5 percent of the countries provided information based on statistical sampling techniques to collect national-level field data, such as that provided by NFIs (Saket, 2002). Following this finding, in the 2000s, Brazil, Costa Rica, Ecuador, Guatemala, Honduras, Nicaragua and Peru were the LAC countries supported by FAO in the planning, design and implementation of their multipurpose NFIs, with national coverage and continuous monitoring. Other countries such as Argentina, Chile and Mexico also implemented similar NFIs.

Later, due to the rise of the REDD+ mechanism, Colombia, Dominican Republic, El Salvador and Panama started their NFIs, and other countries such as Chile, Honduras and Mexico strengthened their processes, which are currently in the third measurement cycle. In addition, Argentina, Costa Rica, Ecuador, Guatemala and Nicaragua are in the second measurement cycle. Countries and territories with more recent processes include the Bahamas, Belize, French Guiana, Guadeloupe, Jamaica, Martinique and Suriname.

Special cases are Puerto Rico and the United States Virgin Islands, which are part of the Forest Inventory and Analysis (FIA) of the United States of America, which started in 1998 and 2004, respectively.

Another milestone in the history of NFIs may be determined by the need for information to respond to national and global strategies for ecosystem restoration, as the period 2021–2030 has been declared the United Nations Decade on Ecosystem Restoration (Resolution 73/284, 2019). National forest inventories are a very important source of information to facilitate the implementation of restoration policies and to report on their progress (Ramírez and Morales, 2021).

1.4 EXPERIENCES IN THE HARMONIZATION OF NATIONAL FOREST INVENTORIES

The harmonization of forest-related definitions and estimates is a key process for clearly understanding what is being measured and reported, as well as for comparing data across countries to facilitate decisions and agreements at national, regional and global levels (Vidal *et al.*, 2016a). Harmonization allows for temporal and geographical comparability without attributing differences to subjective definitions.

At the global level, FAO has facilitated the discussion on the need to harmonize forest data to facilitate the comparability of information from the first FRA in 1948 to the latest assessment presented in 2020 (FAO, 2018b; FAO, 2021b). Figure 1.1 shows the main topics of discussion related to harmonization throughout the history of FRA. The most relevant started in 2000, when terms and definitions for assessments were first drafted. This was followed by the adoption of standardized reporting in 2005 and, in 2010, by meetings to streamline reporting with other international forest-related processes under the Collaborative Partnership on Forests (CPF). The development of the Collaborative Forest Resources Questionnaire (CFRQ), which has been applied since 2015, helped to further simplify and harmonize reporting.

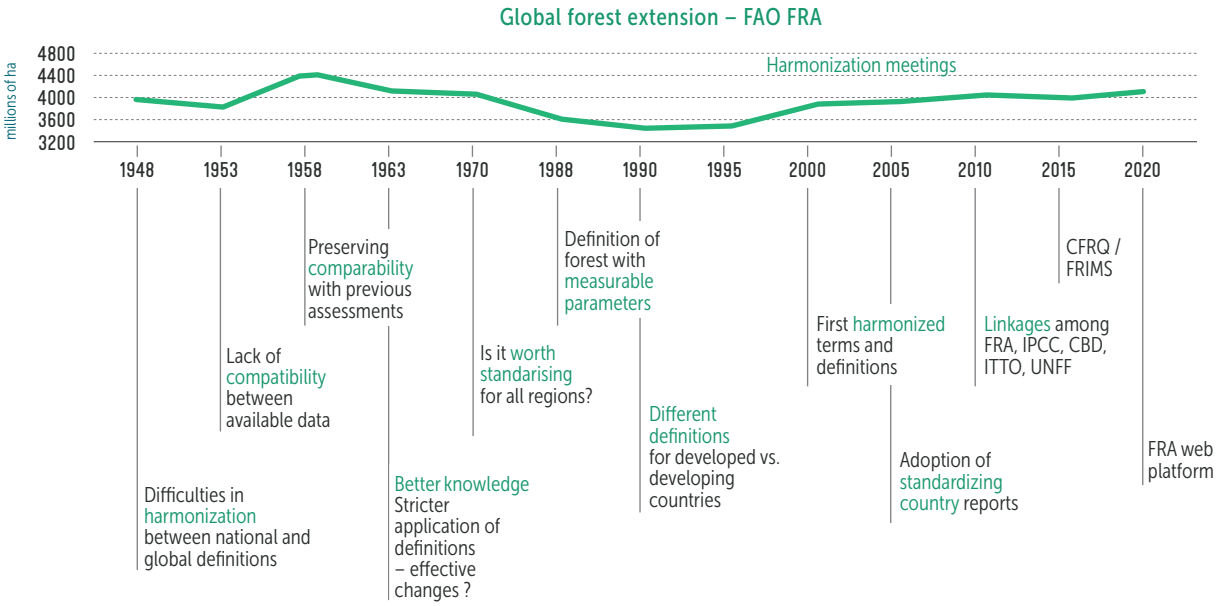
The most recent effort is the development of an online platform (https://fra-platform.herokuapp.com/) where country reports and national, regional and global forest statistics are available (FAO, 2018b).

In order to improve the comparability of information on forest resources in Europe, an analysis of the available information began in the 1990s when the European Forest Information and Communication System was established (European Commission, 1997) and the need for harmonization became apparent. In Europe, in many cases, international statistics are derived from the aggregation of the information provided by the NFIs of each country (as is the case for the FRA); therefore, they are sometimes inconsistent, since the NFIs are independent and data collection protocols differ from one country to another (Tomppo *et al.*, 2010). The European National Forest Inventory Network (ENFIN) was thus established in 2003 to exchange knowledge, strengthen cooperation and promote NFIs as comprehensive monitoring systems by harmonizing information on forest ecosystems (Vidal *et al.*, 2016b). The ENFIN harmonization methodology aims to provide comparable values on forest indicators, including the analysis of sampling designs, definitions of variables, measurement methodologies and data processing. Following the analysis, the harmonization of European NFIs is based on the establishment of commonly agreed reference definitions and functions to transform national indicator values into comparable harmonized values (Tomppo and Schadauer, 2012; Gschwantner *et al.*, 2019).

Since 2015, the countries located in North America (Canada, Mexico and the United States of America) have organized a working group on national forest inventory and monitoring, mandated to support the reporting and assessment of sustainable forest management criteria and indicators through data sharing, scientific collaborations in inventory, monitoring and assessment, developing compatible approaches to forest inventory data, evaluating the use of remote sensing to improve forest data, building capacity and communicating joint results (NAFC, 2000). Based on the map of ecological zones defined by FAO, the working group has succeeded in harmonizing national forest inventory data from the three countries into a North American Forest Database (https://datosforestal.nfis.org/en/), which currently provides information on three indicators: forest area, volume and above-ground biomass.

FIGURE 1.1

History of Global Forest Resources Assessment harmonization processes



Notes: CBD: Convention on Biological Diversity; CFRQ: Collaborative Forest Resources Questionnaire; FAO: Food and Agriculture Organization of the United Nations; FRA: Global Forest Resources Assessment; FRIMS: Forest Resources Information Management System; IPCC: Intergovernmental Panel on Climate Change; ITTO: International Tropical Timber Organization; UNFF: United Nations Forum on Forests.

Source: Adapted from **FAO.** 2018b. *1948-2018: Seventy years of FAO's Global Forest Resources Assessment. Historical overview and future prospects.* Rome, FAO. (2018b, 2021b).

1.5 LATIN AMERICAN AND CARIBBEAN NATIONAL FOREST INVENTORY NETWORK

Inspired by the experiences in Europe and North America, and the need to improve international reporting with regard to comparability and transparency, LAC countries started the harmonization processes with this publication, which has taken two years to produce. In addition to the development of the national chapters in Part II of this publication, working groups were organized to analyse the differences and similarities of NFIs (Chapter 2), the future prospects of NFIs (Chapter 3) and the challenges and opportunities (Chapter 4). The process also prompted the establishment of a working group on the importance of making NFI data accessible in order to improve the transparency of information in international reports (Chapter 5).

Parallel to the development of this publication, regular work sessions are being organized for the harmonization of the prioritised variables: forest area/forest definition, volume and biomass, for which questionnaires have been prepared and answered by the participating countries.

The results of this process are expected to be presented in a second publication.

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The initial activities that were conducted as a means of knowledge and unification among LAC countries have been identified and presented above. As a result of these initiatives, the participating countries are willing to continue working together to form the Latin American and Caribbean NFI network.

Based on the Manaus (Braun *et al.*, 2017) and Costa Rica (Argüello *et al.*, 2018) meetings, the network provides the following benefits:

- Strengthens LAC NFIs through dialogue and exchange of technical, scientific and technological knowledge between NFI managers in different countries, other supporting institutions and institutions responsible for international processes.
- Enhances the use of NFIs for national and international policy decision-making.
- Facilitates the development, implementation and monitoring of forestry strategies in the region through the generation of harmonized statistics.
- Promotes transparency in international reporting, such as FRA, SDGs and reporting to the United Nations Framework Convention on Climate Change (UNFCCC), the CBD and the United Nations Convention to Combat Desertification (UNCCD).
- Provides recommendations for improving international reporting, in particular FRA reports and GHG inventories from the forest sector for reporting to the UNFCCC.
- Promotes regional organization and facilitates funding mobilisation for the sustainability of NFIs.

Figure 1.2 shows the 21 countries currently participating in the network; it is expected that other countries with established NFIs may join in the next steps.

FIGURE 1.2

Map of participating countries in the Latin American and Caribbean national forest inventory network

The boundaries shown and the names and designations used in this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Dotted lines on maps represent approximate boundaries for which there may not yet be full agreement.

Source: Prepared by the authors.

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Chapter

SIMILARITIES AND DIFFERENCES IN THE DESIGN OF NATIONAL FOREST INVENTORIES IN LATIN AMERICA AND THE CARIBBEAN

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2.1 INTRODUCTION

Design and planning are operational elements of national forest inventories (NFIs) for the cost-efficient collection of high-quality data. They should have a scientifically robust basis to meet the credibility principle, and consider available resources to meet the feasibility principle, according to the *Voluntary Guidelines on National Forest Monitoring* (FAO, 2017).

The process of planning and designing NFIs must consider objectives, information needs, geographic coverage (national or subnational), definitions of variables to be measured and availability of resources (Vidal *et al.*, 2016; Ramírez, 2012; Schreuder, Ernst and Ramirez-Maldonado, 2004). It is done through an iterative process in which accuracy requirements or budgets are adjusted according to the information needs, national circumstances and technical, financial and human capacities (FAO, 2017). In addition, processes must be participatory and engage national experts who influence the more specific decisions on the NFI design. Moreover, to frame the sampling design of NFIs efficiently, the following criteria should be taken into account to answer the questions about monitoring: the priority variables or attributes, the variability of data on priority attributes and the precision expectation to be defined (McRoberts *et al.*, 2013; Schreuder, Ernst and Ramirez-Maldonado, 2004). These conditions will determine the similarities and differences in NFI methodologies and designs.

National forest inventories in Latin American and Caribbean (LAC) countries are based on probability sampling, where sampling units were selected and assigned following valid probability criteria that allow population inferences to be made. These conditions allow NFIs to produce information on estimates of the attributes of interest, based on a robust and reliable scientific basis (McRoberts *et al.*, 2013; Schreuder, Ernst and Ramirez-Maldonado, 2004). Data are collected through measurements and observations on plots (areas of specific size in the field). In the case of LAC NFIs, plots have a fixed size, but the configuration varies across countries

– in size, shape and number per sampling unit – due to differences in the attributes to be measured, variability, precision expectation, costs and specific conditions of their forest ecosystems, such as size and distribution of trees and forest structure (Kleinn *et al.*, 2015).

2.2 METHODOLOGY

The purpose of this chapter, as an initial harmonization process, is to describe and analyse the similarities and differences in LAC NFI designs. The analysis focuses specifically on elements of planning, sampling design and the configuration of sampling units, which are essential to understand how data are collected and the conditions or challenges that may arise in harmonizing forest information in the region.

The information was compiled through a questionnaire answered by 20 countries. This information is complemented by the information provided in the 21 country chapters in Part II of this volume (Chapters 6 to 26). The questionnaire was organized in five blocks to cover different aspects of NFIs. The information consulted in each block was related to the following topics: i) general NFI planning; ii) remote sensing; iii) sampling design; iv) sampling unit configuration and v) measurements. The questionnaire was prepared in two languages (Spanish and English) and 35 questions were asked to collect detailed information on the NFIs of LAC countries.

2.3 RESULTS

2.3.1 PLANNING AND SAMPLING DESIGN OF NATIONAL FOREST INVENTORIES IN LATIN AMERICA AND THE CARIBBEAN

Depending on planning and the way they are implemented, NFIs can be periodic and continuous; in such cases, they are permanent and are repeated in cycles that typically vary from five to ten years in LAC. On the other hand, there are NFIs that are designed to be temporary, in the sense that they collect information for a one-off assessment and thus are not planned to replicate measurements.

The vast majority of LAC countries (86 percent) planned their NFIs as periodic and continuous (Argentina, Bahamas, Belize, Brazil, Chile, Colombia, Costa Rica, Ecuador, French Guiana and the islands of Martinique and Guadeloupe, Guatemala, Honduras, Jamaica, Nicaragua, Mexico, Panama, Peru, Puerto Rico, United States Virgin Islands). Only 14.3 percent of the countries planned NFIs for a temporary evaluation (Dominican Republic, El Salvador, Uruguay).

Periodic and continuous NFIs assess changes in forest characteristics that allow information to be compared over time, for example, whether a certain sector of a forest is growing or being degraded. Some 76 percent of LAC countries carry out measurement cycles every five years. Only two countries (Chile and Costa Rica) have a shorter measurement cycle (four years), while only one country (Dominican Republic) established a ten-year measurement cycle for its NFI. Completing sampling cycles requires a great deal of resources and planning, which means that in certain countries the complete closure of an NFI measurement cycle takes longer than planned. This can hamper comparability and increase the variability of information.

In some cases within the same cycle, data measurements are organized by applying panels. Typically, panels consist of annual measurements of a subsample; for instance, an annual panel may contain 20 percent of the sampling units of the population or subpopulation, thus completing an NFI cycle in five years. In LAC countries, 33 percent of the countries conduct panels or sampling unit measurement campaigns on an annual basis. A higher percentage of countries (66 percent) do not use annual panels, but apply panels that segment measurements according to regions. In those countries where such regionalised panels are applied, 60 percent manage to meet the measurements within the planned year. As most LAC countries do not apply annual panels in their NFIs, results reports are produced at the end of the full measurement cycle; this is the case in 52.4 percent of the countries. Only 24 percent of countries report on an annual basis or to meet another criterion, for instance, to complete measurements within a certain political jurisdiction. There are five countries (24 percent) that have no pre-planned frequency for the submission of their NFI reports.

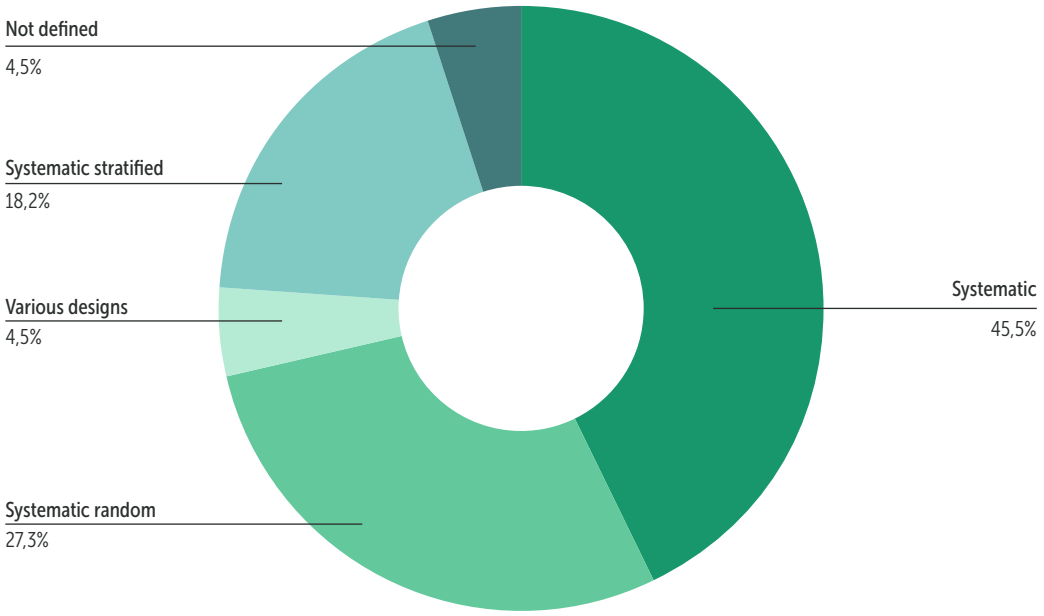
Once the planning of the NFI has been determined, the sampling design must be established, including the number of samples and the way they are selected in the territory or population of interest. There are various strategies to select the sampling units, but it is important to use probability sampling to reduce subjectivity and to have a strategy that best captures the heterogeneity of the forest at the lowest cost (McRoberts *et al.*, 2013).

In the NFIs of LAC countries, 43 percent determine the spatial location of the sampling units systematically without prior stratification. A total of 29 percent of the countries define the location of sampling sites using a combined systematic and random selection strategy, with the objective of obtaining a random sample while ensuring a balanced distribution over the territory; by contrast, 19 percent of the countries use a systematic and stratified strategy. One country uses several selection methods because it has several subnational inventories, while only one country in the region has not yet defined the strategy to be implemented (Figure 2.1).

Another relevant feature of NFIs is to determine whether the sampling units are temporary or permanent. According to the *Voluntary Guidelines on National Forest Monitoring* (FAO, 2017), it is recommended to establish sampling units on a permanent basis for periodic or continuous NFIs. To achieve this, measurement procedures should record accurate coordinates in a geographical reference system and obtain reference points for future data collection at the same sampling site. In LAC, 76 percent of the NFIs establish permanent sampling units, which ensures that in successive cycles, measurements are made at the same site. By contrast, 14 percent measure all of the sampling units on a temporary basis, that is, data are not taken at the same sites in different NFI cycles, and 10 percent of countries have both permanent and temporary sampling units (Figure 2.2).

FIGURE 2.1

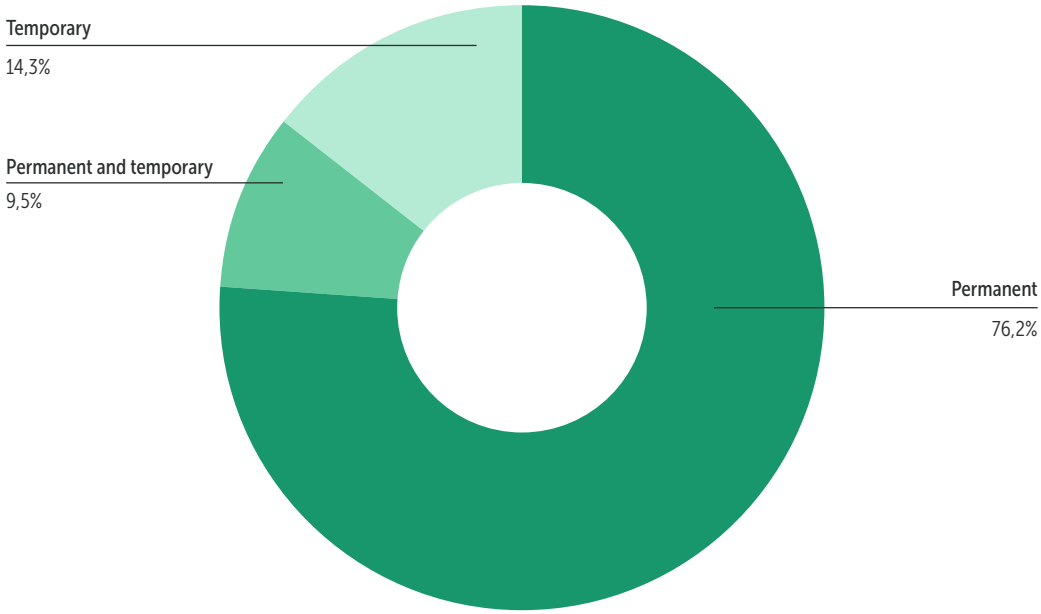
Types of sampling designs of national forest inventories in Latin America and the Caribbean



Source: Prepared by the authors.

FIGURE 2.2

Type of sampling units of national forest inventories in Latin America and the Caribbean according to their temporality



Source: Prepared by the authors.

2.3.2 USE OF REMOTE SENSING TOOLS IN NATIONAL FOREST INVENTORIES

The use of remote sensing in NFIs is recommended in order to support their implementation and to achieve greater impact of data use; in addition, remotely sensed observations can be used as auxiliary variables to improve estimates (pre- or post-stratification) (McRoberts and Walters, 2012). It can also be used on sites where field measurements are not possible, when data need to be produced at a smaller scale than the NFI scope or to calculate modelling-based statistics (wood volume, biomass, carbon, etc.) (Kangas *et al.*, 2019). The implementation of remote sensing in NFIs brings multiple benefits and, therefore, 95 percent of LAC countries use it.

Remotely sensed information is also very useful during the planning and sampling design stages. Eighty percent of LAC countries apply remote sensing information to improve forest inventory planning. Between 65 percent and 70 percent of the countries use these tools in sampling design to determine areas of forest, non-forest and other land uses as a stratification criterion prior to sampling. Fifty percent of countries use forest type maps for post-stratification of data and for outcome mapping of variables measured in sampling units (Figure 2.3).

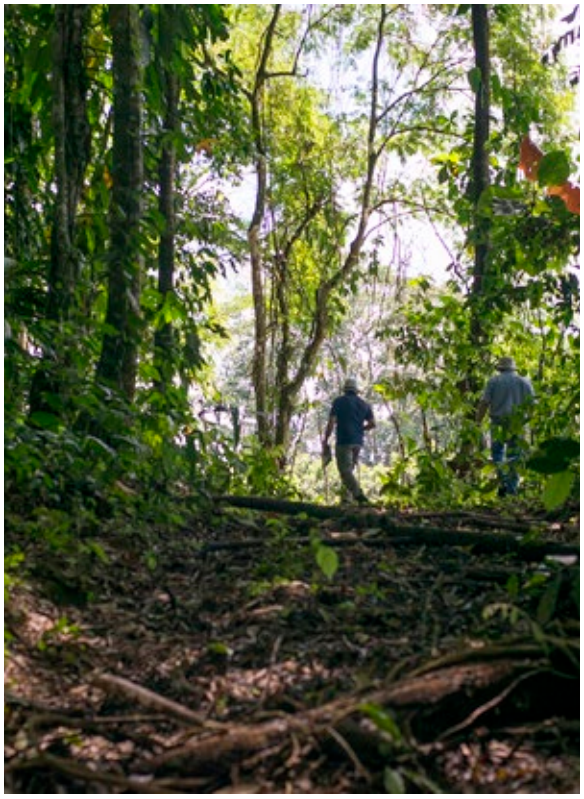


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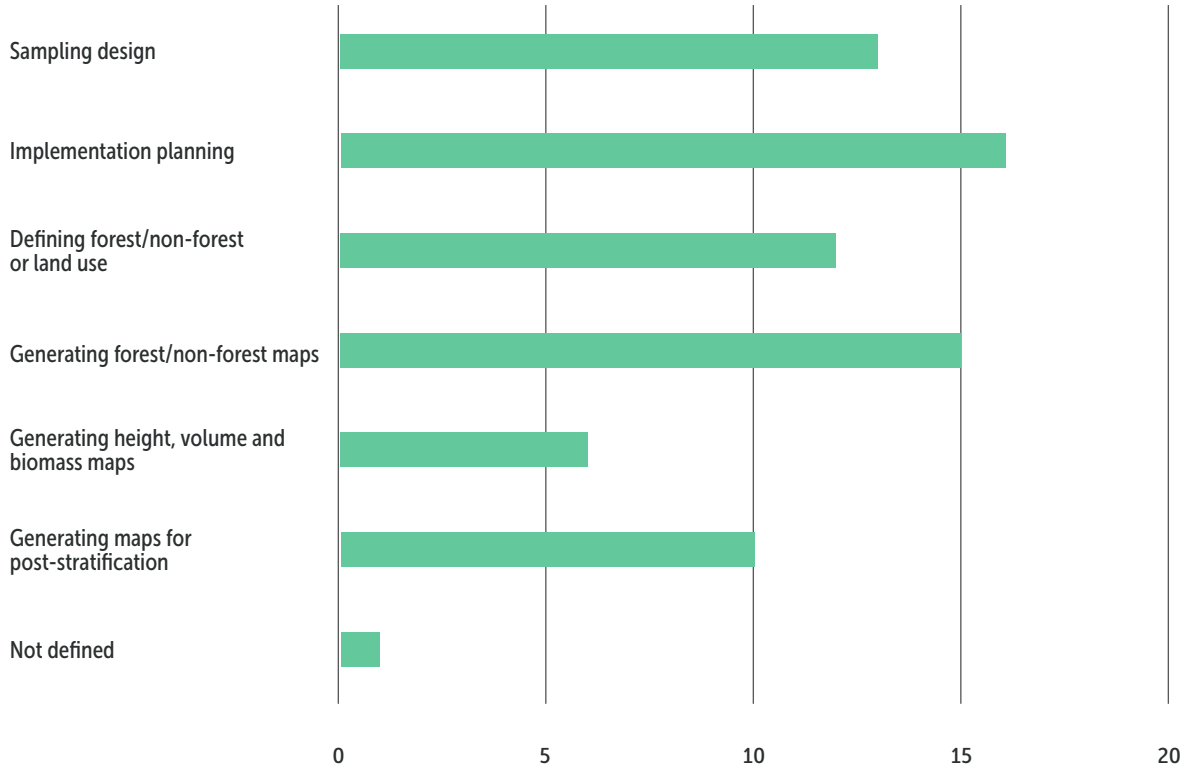
FIGURE 2.3

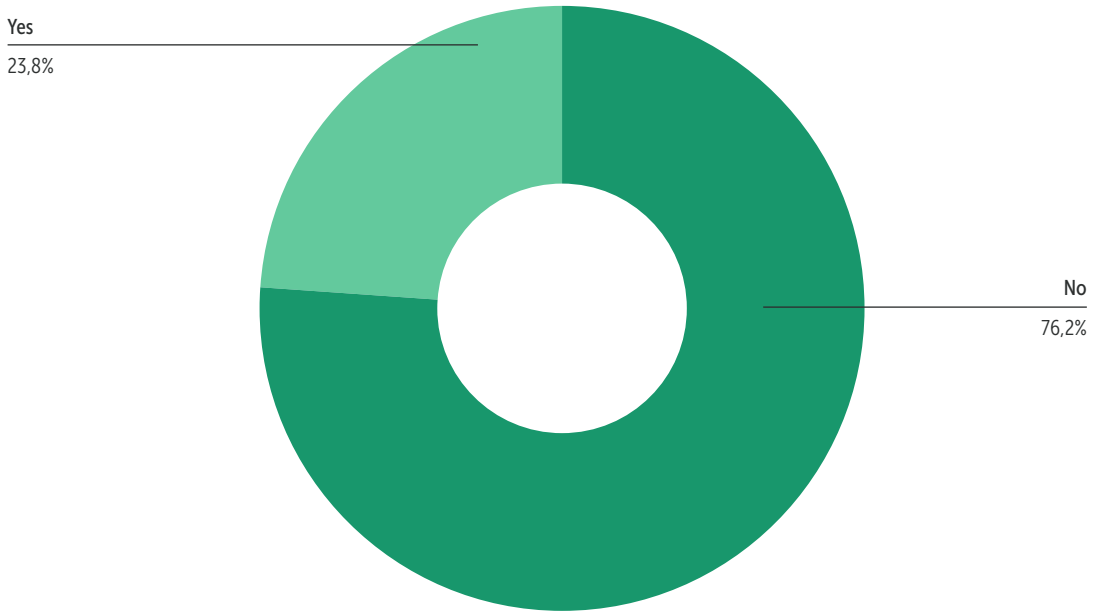
Activities where remote sensing is used in national forest inventories in Latin America and the Caribbean



Source: Prepared by the authors.

FIGURE 2.4

Countries that have a technical team for national forest inventory requirements



Source: Prepared by the authors.

To ensure that NFIs are properly implemented, National Forest Monitoring Systems require technical staff with knowledge and experience in field measurements, data processing, information management and the use of remote sensing tools (FAO, 2017). Despite the wide use and application of remote sensing in LAC countries, only five countries (24 percent) have a dedicated team of technicians for NFI needs (Figure 2.4). This situation could lead to difficulties in the use of remote sensing in NFIs.

In relation to products stemming from the use of remote sensing tools, only 19 percent of countries have vegetation maps made with satellite images that are less than two years old. The majority of countries (57 percent) have vegetation maps for their NFIs that are between two and five years old, while 23.8 percent of the countries use vegetation maps from satellite images that are between five and ten years old (Figure 2.5).

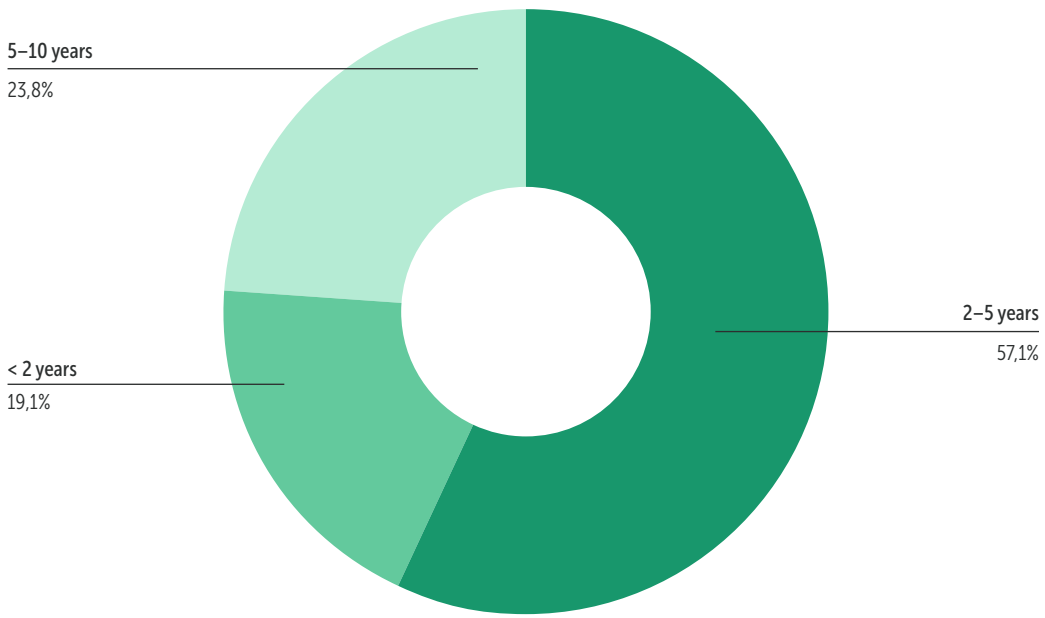
2.3.3 SAMPLING UNIT CONFIGURATION

An important aspect in the methodological design of NFIs is the choice of the spatial configuration pattern of the sampling units. Determining the spatial configuration includes several aspects, such as whether the sampling units are defined as a cluster or single, whether the shape of the sampling unit is square, rectangular or circular (among other possible shapes), or whether the sampling unit has subdivisions (McRoberts *et al.*, 2013). These aspects of the sampling unit respond to various needs for improvements in data collection dynamics, cost optimization and to capture greater forest heterogeneity.

In LAC, there are differences between the NFIs in terms of plot configuration: 68 percent use cluster plots, while 23 percent of the countries use individual plots. There are individual cases such as El Salvador, which has two types of NFI sampling unit configurations: individual plots are used in broadleaved forest, coniferous forest and shaded coffee plantations, while cluster sampling units are used in mangroves. French Guiana, Martinique and Guadeloupe are currently in the process of defining the design of their sampling unit configuration (Figure 2.6).

FIGURE 2.5

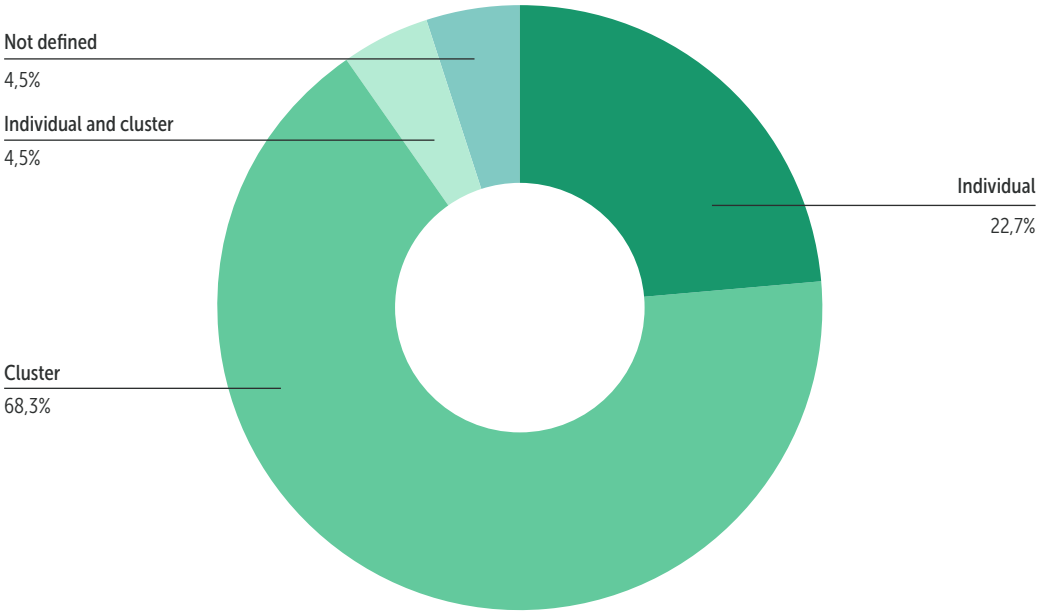
Availability of vegetation maps



Source: Prepared by the authors.

FIGURE 2.6

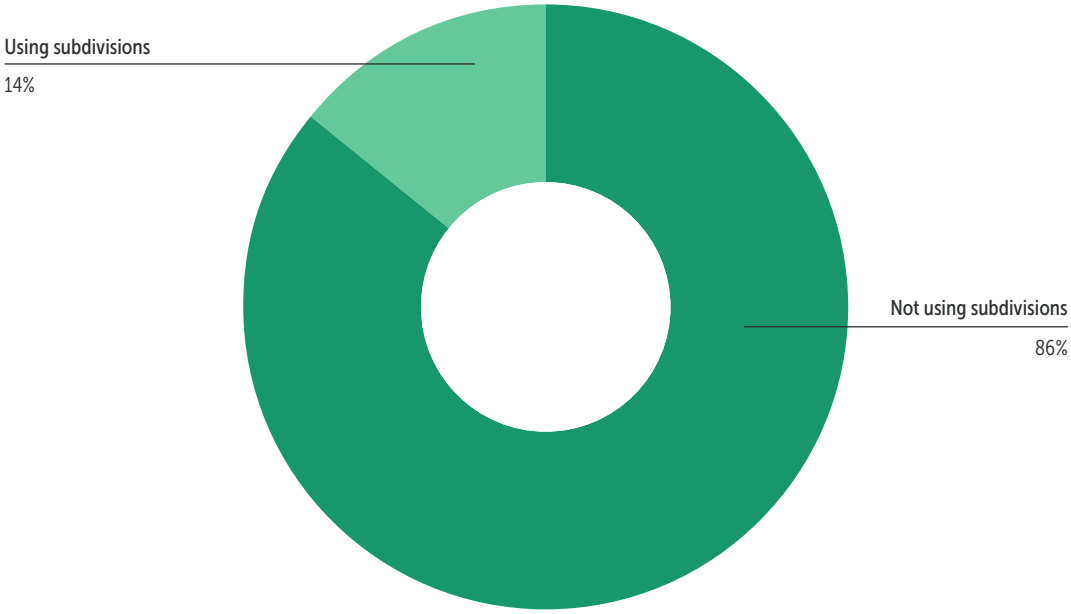
Sampling unit configurations used in national forest inventories in Latin America and the Caribbean



Source: Prepared by the authors.

FIGURE 2.7

Use of plot subdivisions in national forest inventories in Latin America and the Caribbean



Source: Prepared by the authors.

Among the countries using cluster sampling units, there is some disparity in terms of the number of plots chosen: 54 percent of the countries use three plots, while 40 percent of the countries use four plots. Colombia uses five plots, Bahamas uses two plots, while Peru has two types of sampling units depending on the subpopulation: ten plots are used for the highland tropical rainforest, coastal range and hydromorphic zone, while seven plots are used for the lowland tropical rainforest subpopulation.

There are several factors to consider when deciding on the shape of sampling units. Important aspects include forest structure, prioritised variables for measurement, practical and technical aspects, and reducing the edge effect or the practicality of remeasuring information (Kleinn *et al.*, 2015). For example, in the NFIs of Honduras (ICF, 2020) and Guatemala (INAB and CONAP, 2020), it was decided to change from rectangular to circular sampling units due to the ease of remeasuring and the reduction of the edge effect. In circular sampling units, only one point is required to subsequently locate trees, while in rectangular sampling units, locating the same trees in future assessments is more difficult since at least four reference points are required for the correct location. While it is important to know the shape and layout of the sampling units in the framework of NFI harmonization, errors due to the shape of the sampling unit may be a minor issue in relation to other sources of error related to the design. Measurement-related errors can be minimised through good training of field crews and quality control of the information collected.

The prevailing plot shape within LAC countries is circular (50 percent), while 25 percent of the countries use rectangular plots. There are specific cases such as Belize and Ecuador that use square plots, or El Salvador and Peru that have determined a combination of circular and rectangular plots for their NFIs, depending on the type of forest. In addition, within the countries that use cluster plots, four countries use an inverted "Y" configuration of subplots, two countries adopt a cross configuration, while Ecuador and Peru use an "L" configuration.

Another crucial factor in designing sampling units is to achieve greater sampling efficiency. Many countries have subdivided the plots. This strategy improves various aspects of NFIs, such as the time spent for data collection and obtaining more accurate information on different variables of interest at lower cost. Eighty-six percent of LAC countries use a subdivision within plots (Figure 2.7).

2.3.4 ADDITIONAL INFORMATION COLLECTED IN THE SAMPLING UNITS

Traditionally, NFIs collect data on dasometric variables such as species, total height, stem or commercial height, diameter at breast height and habits of woody plants. However, the development of NFIs has incorporated new descriptive forest variables such as fallen dead wood, soil organic carbon, vegetation cover, and identification and measurement of other life forms, among others. The variables included in the NFIs respond to each country's needs for a better characterization of forests and their biodiversity and to their international reporting commitments.

At present, NFIs are multipurpose and several variables are measured simultaneously during the same visit to the sampling units. In recent years, determining the amount of carbon in forests has gained importance because it is relevant information for climate change mitigation strategies. There are important variables to harmonize in NFIs related to carbon sinks, namely soil carbon and fallen dead wood. In LAC, 57 percent of NFIs take soil samples in order to determine the organic carbon content, and they add this carbon stock to that found in vegetation. Only Brazil, Mexico and Panama use soil samples to obtain additional information related to nutrients and other soil characteristics.

In relation to the information provided in the NFIs related to fallen dead wood, 90 percent of the countries include variables to determine standing dead wood, stems, fallen branches and fine dead wood. To collect this information, most NFIs use the line or transect sampling method. Nicaragua and Uruguay do not use this variable.

All LAC countries reported that during the development of their inventories they collect information related to plant life forms other than trees, such as shrubs, herbaceous vegetation, bamboo, palms, lianas and vines. Puerto Rico and the United States Virgin Islands do this optionally, while the rest of the countries implement this on a regular basis. Sixty-seven percent of countries record variables such as quantity (number of

plants per hectare) and size of plants, while the Bahamas, El Salvador, Guatemala, Nicaragua and Peru only count the number of plants. On the other hand, Argentina, Guatemala and Uruguay quantify understorey and herbaceous stratum cover based on horizontal crown projection percentages of the life forms analysed in their NFIs.

2.4 CONCLUSIONS

Table 2.1 presents a summary of general aspects of sampling designs that may reveal differences in reports generated from NFIs.

In the LAC region, most countries conduct their NFIs with a view to medium- or long-term monitoring. However, there are countries that have designed the NFI to measure and record data only once for a single specific cycle (temporary NFI), which limits harmonization with the rest of the countries.

National forest inventories with five-year cycles prevail in the region and sampling units tend to be permanent rather than temporary, enabling comparisons over successive cycles. In addition, most countries use a systematic sampling design using a grid of square or hexagonal polygons. Only a few countries selected the sample randomly within each polygon, resulting in random sampling distributed evenly across the territory. In the LAC region there are a total of 67 311 sampling units. Therefore, it should be expected that the form and structure of sampling units will vary between the different NFIs. Although some countries still use individual plots, the trend is to sample from cluster plots. The theory behind this design is that a group of plots better captures variability within the entire sampling site, compared to a single plot of equal or greater area. This strategy allows for a reduction of time and resources in the data collection process relative to implementing large sampling units (McRoberts *et al.*, 2013).

In LAC NFIs there is a strong field data component that often requires a greater commitment of resources to ensure sufficient sampling (trained technicians, vehicles, equipment, inputs, etc.), especially in large, heterogeneous and highly diverse landscapes. At the same time, most countries use remote sensing tools in their NFIs. This provides certain advantages, including the possibility of reducing costs, updating information more frequently and obtaining more complete forest cover data without problems of inaccessibility or denied access, among other benefits (McRoberts *et al.*, 2006). Furthermore, NFIs in the region are multipurpose. Thus, in most countries, information is collected on various variables such as dead wood or soil organic carbon, in addition to the classic dasometric variables that characterize forest structure.

Given the diversity found among NFIs in LAC countries, it is essential to document NFI processes (FAO, 2020). Transparent and complete documentation is of vital importance in order to clarify these differences for the users of forest data.

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TABLE 2.1

Comparison of sampling designs for national forest inventories in Latin America and the Caribbean

Country	Country area (1 000 ha)	NFI temporality	Sampling design	Sampling cycle	Plot location	Type of plots	Plot shape	Number of plots per cluster	Sample size
Argentina	273 669	Periodic	Systematic	5 years	Permanent	Individual	Circular	n/a	4 158
Bahamas	1 001	Periodic	Random systematic	5 years	Permanent	Cluster	Circular	2	114
Belize	2 280	Periodic	Various designs	5 years	Permanent	Individual	Square	n/a	60
Brazil	845 651	Periodic	Systematic	5 years	Permanent	Cluster	Cross-shaped square	4	17 587
Chile	74 880	Periodic	Systematic	4 years	Permanent	Cluster	Circular	3	1 109
Colombia	103 870	Periodic	Random systematic	5 years	Permanent and temporary	Cluster	Cross-shaped circular	5	1 479
Costa Rica	5 106	Periodic	Systematic	4 years	Permanent	Individual	Rectangular	n/a	441
Dominican Republic	4 838	Temporary	Stratified systematic	10 years	Temporary	Individual	Rectangular	n/a	424
Ecuador	27 684	Periodic	Stratified systematic	5 years	Temporary	Cluster	L-shaped squares	3	1 744
El Salvador	2 072	Temporary	Random systematic	5 years	Temporary	Individual and clusters	Rectangular and circular in a line	5	319

TABLE 2.1 (CONTINUED)

Country	Country area (1 000 ha)	NFI temporality	Sampling design	Sampling cycle	Plot location	Type of plots	Plot shape	Number of plots per cluster	Sample size
French Guiana, Martinique and Guadalupe	8 815 169 106	Periodic	Not defined	Not defined	Permanent and temporary	Not defined	Not defined/ tends to be rectangular	n/a	n/a
Guatemala	10 843	Periodic	Random systematic	5 years	Permanent	Cluster	Circular in a line	3	715
Honduras	11 189	Periodic	Random systematic	5 years	Permanent	Cluster	Circular in a line	3	635
Jamaica	1 083	Periodic	Systematic	5 years	Permanent	Cluster	Circular in inverted Y shape	4	428
Mexico	190 869	Periodic	Stratified systematic	5 years	Permanent	Cluster	Circular in inverted Y shape	4	26 220
Nicaragua	12 140	Periodic	Systematic	5 years	Permanent	Cluster	Circular and rectangular	4	371
Panama	7 443	Periodic	Stratified systematic	5 years	Permanent	Cluster	Rectangular	4	92
Peru	128 000	Periodic	Random systematic	5 years	Permanent	Cluster	L-shaped circular L-shaped square	7 and 10	7 293
Puerto Rico	887	Periodic	Systematic	5 years	Permanent	Cluster	Circular in inverted Y shape	4	581
Suriname	15 600	Not defined	Systematic	Not defined	Not defined	Cluster	Rectangular	8	42
United States Virgin Islands	34	Periodic	Systematic	5 years	Permanent	Cluster	Circular in inverted Y shape	4	116
Uruguay	17 502	Temporary	Systematic	5 years	Permanent	Individual	Rectangular	n/a	2 916

Note: NFI: national forest inventory; n/a: not applicable.

Source: Prepared by the authors.

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NEXT CHAPTER

Chapter

FUTURE PROSPECTS FOR NATIONAL FOREST INVENTORIES IN LATIN AMERICA AND THE CARIBBEAN

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3.1 INTRODUCTION

The purpose of this chapter is to summarise the future prospects for NFIs in Latin America and the Caribbean (LAC): the continuous monitoring of forests, the analysis of the main methodological similarities, differences and challenges presented by the countries of the region on the subject. It is considered important to know the trends and plans that NFI officials have for their future development, as well as the concrete actions that can be employed to resolve the challenges they face.

The results and conclusions presented in this chapter are drawn both from the analysis of the reflections in the "future prospects" section of the 21 national chapters in Part II of this book, as well as from a specific questionnaire designed to standardize the criteria for analysis. The questionnaire covered elements of data collection, information management and institutional aspects, and was completed by 20 countries.

The status, characteristics and contexts of national forest inventories (NFIs) in LAC are very diverse and their analysis requires an understanding of the short- and long-term objectives and goals of each country. As described in the national chapters, there are countries that have not yet completed the first measurement cycle (that is, with the complete installation of sampling units), while others have already begun the second or third cycle of forest monitoring. There is also a great diversity of variables sampled and ways of collecting information in the field that enrich the analysis. Continuity in forest monitoring is a priority for most countries in the region, and the institutional or external funding to support this work, as well as the availability and retention of trained human resources, are some of the challenges to meeting this objective.

National forest inventories produce relevant information for the management, planning and establishment of forest policies aimed at conservation and/or sustainable resource management, through the integration of urban and rural communities and society as a whole. Moreover, data obtained from the inventories provide information for the preparation of national and international studies and reports, among other aspects highlighted by the countries included in this publication.

FIGURE 3.1

Perspectives on future improvements of national forest inventories by number of countries and areas of interest (n = 21)

Source: Prepared by the authors.

3.2 FUTURE PROSPECTS IN LATIN AMERICA AND THE CARIBBEAN

Future prospects for the development of NFIs in the LAC region can be drawn from the accumulated experiences in planning, implementation, data analysis and reporting of such initiatives. These issues become important in seeking continuous improvements to strengthen the basis for sustainable management planning of forest ecosystems, according to the specific context of each country.

This section analyses the future prospects of the countries in the region, organized in three blocks: i) data collection methodology, which includes the incorporation of new variables and technologies for monitoring; ii) information management, related to its application in different national, regional and international reports; and iii) institutional aspects, referring to human and economic resources to continue monitoring.

Considering the above-mentioned aspects, according to the national chapters, 95 percent of countries (20 countries) expressed the need to make changes and improvements to the methodology of data collection in their NFIs. A total of 43 percent (9 countries) referred to data management and 62 percent (13 countries) reported the need for improvements related to institutional arrangements (Figure 3.1). It is worth mentioning that very few countries (namely, Guatemala, Honduras, Mexico, Nicaragua, Peru and Uruguay) integrated all three perspectives into their national chapter reflections. In most cases, the final discussion focused on one or two of these thematic areas, the most important being the data collection methodology and the need to rethink it in the future.

3.2.1 DATA COLLECTION METHODOLOGIES

Data collection methodologies in NFIs refer to the strategies and procedures for implementing, developing and completing the planned sample design. This includes aspects related to the collection of field data, protocols, coordination of the staff and use of technology. Methodologies for collecting data are being continuously refined thanks to the exchange of experiences and limitations encountered, as well as the search for improvements and solutions in the process of planning, development and data analysis.

In order to better understand the future prospects of data collection methodologies, the analysis has been divided into two time horizons: i) short term (one to four years) and ii) medium to long term (more than five years).

Short-term outlook

The prospects identified for the short-term time horizon were as follows (Figure 3.2):

- 40 percent of respondents mentioned finalising the installation of field sampling units and implementing new NFI cycles, from which new ideas and needs will emerge in the data collection phase;
- 50 percent of the respondents referred to improvements in sampling design, including the increase of sample size;
- 10 percent of respondents mentioned improvements in field data collection and use of modern technologies.

Medium- to long-term outlook

The medium- and long-term prospects mentioned were as follows (Figure 3.2):

- assessment of new forest types and other land use categories (14 percent);

- assessment of information needs (48 percent);
- introduction of modern technologies in field data collection and remote sensing (38 percent).

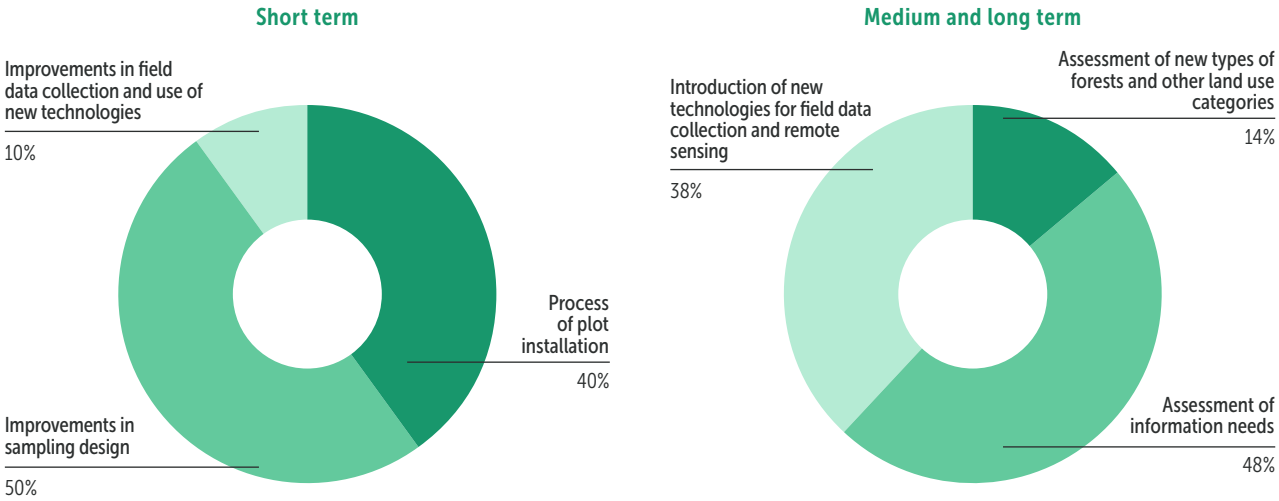
The assessment of new forest types and other land use categories is driven by the need to standardize and define the areas to be assessed when developing forest inventories at the national scale. The increasing diversification of forest resource use is a prominent feature of FAO's series of voluntary guidelines on forest monitoring (FAO, 2017). This situation results in the progressive need to include all land with trees in inventories, and not solely land that is defined as forest. This is particularly important given that there is a group of countries that collect information specifically in forest areas, including Argentina, Chile, Ecuador, Puerto Rico, United States Virgin Islands and Uruguay. Of this group, Ecuador, Puerto Rico, United States Virgin Islands and Uruguay include planted forests, but Argentina and Chile include only native forests. Another group of countries plans to integrate information on forest resources across all types of land use in the future, which implies measuring "trees outside the forest" (El Salvador, Guatemala, Puerto Rico and United States Virgin Islands).

These assessments are needed to generate more reliable information on the state of the different forest ecosystems and resources found throughout the region.

The comprehensive assessment and analysis of the information needs and requirements, as well as the variables to be collected during each measurement cycle, are part of the strategic elements to support the methodological design and implementation of NFIs (FAO, 2017). In this regard, the evaluation of the development and completion of previous cycles is essential for improving implementation and evaluation, in order to determine whether there are any existing needs related to the variables being collected, based on the learning experiences in the previous cycles. This should be undertaken by multiple stakeholders involved in planning, development and information analysis; the requirements of international commitments also need to be included, as well as an assessment of the importance and role of local communities. In general, information needs can be grouped into the following categories: i) harvesting/management of wood products; ii) biodiversity and conservation (other forms of life and wildlife); iii) socioeconomic issues; iv) non-wood forest products; v) greenhouse gas emissions (deforestation, degradation); and vi) ecosystem restoration.

FIGURE 3.2

Future prospects for data collection methodologies as projected in the short term and medium to long term (n = 21).



Source: Prepared by the authors.

Finally, the introduction of modern technologies to improve data capture, recording and storage procedures helps to optimize human and economic resources, as well as time investments. Technology should help to i) generate information that provides better quality measurements, for example, with the use of tablets and terrestrial or aerial LiDAR (light detection and ranging) and drones; ii) improve data accuracy by using satellite images to conduct pre- or post-stratification of measurements; or iii) draw up maps by combining satellite images to show results or aerial LiDAR to extrapolate variables such as volume and biomass based on models in areas where access and field measurements are not possible.

Improvements to national forest inventory designs

This section presents the main improvements to the NFI designs based on the responses to the questionnaire. Among the aspects to be modified in the NFIs, although there is a group of countries (35 percent) that do not envisage any changes to the design, the majority of countries (65 percent) referred to some changes in the future regarding the design, intensification, implementation and inclusion of other categories of land use in the monitoring.

The most relevant aspects mentioned by countries considering changes to their NFI designs in the future were the following (Table 3.1):

- Method for the implementation of measurement cycles, whereby panels or subsampling campaigns are conducted over a specific period of time (for instance, yearly) until the cycle is completed.
- Sampling intensification (refers to the increase of the number of sampling units to be installed in the field).
- Changes to the sampling unit design (for example, changes to the type of sampling unit, such as the transition to a cluster design and/or change in the size of the sampling unit).
- Incorporation of other categories of "other wooded land" as defined by the Global Forest Resources Assessment (FRA) as part of future monitoring.
- Other aspects, such as the inclusion of urban forests and trees outside the forest in the sampling, the inclusion of "other land" as defined by FRA, the time period for completing all NFI sampling units (cycle), and adjustments to the sampling design.

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TABLE 3.1

Prospects for methodological improvements to be implemented in the development of national forest inventories

Aspects	Countries	Number of countries (n = 20)
No plans to change the design of the NFI in the future	Argentina, Chile, Colombia, Costa Rica, French Guiana, Honduras, Mexico	7
Cycle implementation method	Belize, Brazil, Guatemala, Jamaica, Nicaragua, Puerto Rico, Uruguay	7
Sampling intensification	Belize, Brazil, Dominican Republic, Ecuador, Jamaica, Nicaragua, Peru	7
Design of sampling units	Jamaica, Nicaragua, Panama, Peru, Uruguay	5
Incorporation of other categories of "other wooded land" (FRA definition)	Belize, Dominican Republic, El Salvador, Jamaica, Panama	5
Incorporation of urban forests	Brazil, Jamaica, Panama, Puerto Rico	4
Cycle (time period to complete all NFI sampling units)	Brazil, Nicaragua, Peru	3
Incorporation of "other land" (FRA definition)	Belize, El Salvador, Panama	3
Include trees outside the forest	El Salvador, Jamaica, Puerto Rico	3
Sampling design	Ecuador, Jamaica	2
Improvement of stratification; implementation in the whole forest area (refers to the fact that only mangroves have been sampled with the methodology designed for NFIs)	Suriname	1
Move from temporary to permanent sampling units and adjusted to the systematic grid used to determine land use	El Salvador	1

Notes: FRA: Global Forest Resources Assessment; NFI: national forest inventory.
Source: Prepared by the authors.

Sampling of new variables

Among the variables to be incorporated in the NFIs in the future, 5 of the 20 participating countries mentioned that they had no plans to include new variables (Table 3.2); this may be because many of the variables mentioned in the questionnaire are already being collected by some of the countries or they simply do not have such information a priori. Among the variables mentioned, the measurement of soil organic carbon, monitoring of carbon in different forest biomass pools, and the evaluation of shrub and herbaceous vegetation stand out as relevant aspects for the future diagnosis of forest ecosystems in the region. The least mentioned areas were the social aspects of forests; the evaluation of non-woody vegetation such as palms, bamboo and/or tree ferns; the description of the soil profile where forests develop; the land use and history of the forest; the phytosanitary status and natural regeneration.

Another group of variables that were mentioned only once by some of the countries relate to the assessment of climatic variables of the ecosystem; the phytosociological structure of the forest, which refers to tree crown structures, tree inclination and tree stratum (dominant/codominant/suppressed); molecular taxonomy of species; quality, salinity and fauna concerning mangroves; measurement of crown diameter and moisture of detritus samples (Table 3.2).

Finally, it is important to take into account that the information collected in the field sampling units is the starting point for the analysis that generates information on the state, dynamics and composition of the diverse types of forests present in the LAC region. The dasometric information is complemented in some cases with edaphoclimatic, social, economic and biodiversity variables, among others, thus creating a more comprehensive analysis.

TABLE 3.2

Variables to incorporate in the development of future national forest inventories

Variable	Countries	Number of countries (n = 20)
Soil organic carbon	Argentina, Chile, Honduras, Peru, Uruguay	5
Carbon monitoring	Argentina, Belize, El Salvador, Honduras, Nicaragua, Uruguay	6
Shrub and herbaceous vegetation	Argentina, Belize, Costa Rica, Dominican Republic, Puerto Rico, Suriname	6
No plans to include new variables	Ecuador, French Guiana, Guatemala, Mexico, Panama	5
Social aspects	Costa Rica, Puerto Rico, Suriname, Uruguay	4
Vegetation of palms, bamboo and/or tree ferns	Costa Rica, Jamaica, Puerto Rico	3
Soil profile description	Belize, Jamaica	2
Forest use and history	Belize, Costa Rica	2
Phytosanitary status	Costa Rica, Suriname	2
Natural regeneration	Belize, Costa Rica	2
Fauna	Costa Rica	1
Climatic variables	Belize	1
Phytosociological forest structure	Costa Rica	1
Molecular taxonomy	Brazil	1
Water quality, salinity and fauna in mangroves	Suriname	1
Crown diameter	Colombia	1
Moisture of detritus samples	Colombia	1

Source: Prepared by the authors.

The guidelines recommended by international organizations such as FAO (2017) highlight the creation and management of National Forest Monitoring Systems with multiple objectives and according to the particular circumstances (biophysical, institutional, economic, among others) of each country. The ultimate goal of forest inventories is to know the state of our resources so that, based on this initial approach and through the management and processing of this information, guidance can be provided on the management, use and conservation of the resources and services offered by forests.

3.2.2 INFORMATION MANAGEMENT AND PROCESSING

The development of a sound policy on data sharing will enable stakeholders interested in the information produced by NFIs to use it in a timely manner for decision-making (FAO, 2017). National forest inventories are key pillars of National Forest Monitoring Systems because they produce data on multiple variables and can respond to a wide variety of national, regional and international information requests.

Over the last three decades, the demand for information from countries has increased due to commitments to track international policy indicators such as the Sustainable Development Goals (SDGs), nationally determined contributions (NDCs), Reducing Emissions from Deforestation and Forest Degradation (REDD+), FRA, criteria and indicators for sustainable forest management

(C&I SFM), the Aichi Biodiversity Targets of the Convention on Biological Diversity (CBD), the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), the European Union Action Plan on Combating Illegal Logging through forest law enforcement governance and trade (FLEGT), the International Tropical Timber Organization (ITTO), and the Convention on Wetlands of International Importance (Ramsar Convention), among others.

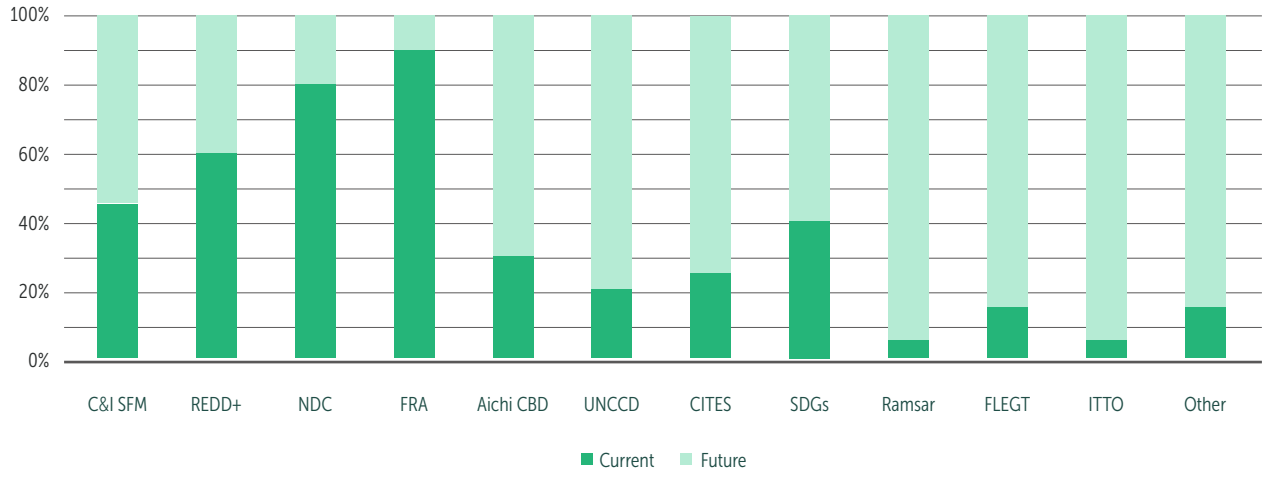
Figure 3.3 shows the use of NFIs by 20 LAC countries to respond to current and future international commitments. As illustrated in the figure, 18 countries use NFIs to respond to FRA. The two countries that do not use their information to meet this requirement is because they have not started collecting data from their NFIs. For NDC, 16 countries use data from their NFIs; for REDD+, 12 countries; for C&I SFM reporting, 9 countries; for SDGs, 8 countries; for Aichi Targets, 6 countries; for FLEGT, 3 countries; for Ramsar and ITTO, 1 country; and for others, 3 countries. On the other hand, most survey respondents said that the future potential of NFIs is for all the above-mentioned requirements.

In addition, due to the relevance of forest information that is directly or indirectly related to different policies (climate change, energy, conservation of natural resources, etc.), countries should make significant efforts to respond to the increasing demands for information. This is why consolidating questionnaires or reports to meet different requirements would be of major help. An example of this is the Joint Forest Sector Questionnaire, an initiative of ITTO, the United Nations Economic Commission for Europe, FAO and Eurostat to compile statistics for the World Timber Situation. The principles of cooperation include that data should be requested only once from each country, that information should be shared among the four organizations, and that each organization should use the information received according to its own mandate (Wardle *et al.*, 2008).

Given the large amount of inventoried data and its relevance, NFIs need to pay special attention to planning tools and platforms to store and manage the information that is collected in a secure way. To this effect, FAO suggests generating a data management model as part of the *Voluntary Guidelines on National Forest Monitoring* (FAO, 2017).

FIGURE 3.3

International requirements where information from national forest inventories is being used or could be used



Notes: Aichi CBD: Aichi Biodiversity Targets of the Convention on Biological Diversity; C&I SFM: Criteria and Indicators for Sustainable Forest Management; CITES: Convention on International Trade in Endangered Species of Wild Fauna and Flora; FLEGT: European Union Action Plan for forest law enforcement, governance and trade; FRA: Forest Resources Assessment; ITTO: International Tropical Timber Organization; NDC: nationally determined contributions; Ramsar: Convention on Wetlands of International Importance; REDD+: Reducing Emissions from Deforestation and Forest Degradation; SDGs: Sustainable Development Goals; UNCCD: United Nations Convention to Combat Desertification.
Source: Prepared by the authors.

Data systems for NFIs can be part of national forest information platforms and should aim for clear and transparent documentation. In addition, harmonizing nationally produced data and developing these data management systems becomes essential for the production of robust forest information (Vidal *et al.*, 2016).

Countries should consider the numerous opportunities for data sharing so that more stakeholders can use the data for decision-making. Since NFIs typically cover a very large set of field variables, often organized in sampling designs that can be complex, the data management model can expand the use of the data by creating protocols for rapid extraction of subsets of data that are appropriate for different users, topics and extensions.

More information on this topic is presented in Chapter 5, which is a call for transparent and open NFI data.

3.2.3 INSTITUTIONAL ASPECTS

The institutionalization of forest inventories is necessary to develop continuous planning and monitoring, through established processes that aim to gather information on the status and dynamics of forests on a regular basis. Defining institutional goals and perspectives is necessary to ensure the permanence of these initiatives, which generate information at national scale.

The countries of the region face different situations in terms of the number of NFI cycles that have been carried out and those that will be developed in the future; however, all countries can draw on their experiences to reflect on technical, administrative and financial aspects. In this sense, one of the greatest challenges is the institutionalization of the NFIs, whereby the needs related to the administration, implementation and financing of activities are covered through government support, considering that the generation of information is the basis for planning the sustainable use of forests.

Institutionalization provides a solid basis to ensure the continuity of NFIs on a regular or cyclical basis, creating linkages to obtain the support of academia, as well as other private organizations, nongovernmental organizations, social groups and any other group that may join in this important work.

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Having permanent and trained technical teams for specific tasks in forest monitoring, as well as an institutional budget in line with the activity, are two key aspects underscored by most of the countries. There is also a need for public policies at the state level aimed at guaranteeing forest monitoring with budgets and other resources to ensure the efficient implementation of these projects. In many countries, the continuity and frequency of NFIs will be determined by the availability of funding sources outside the institutional budget, so their continuity may be jeopardised in the medium term.

Analysing the responses related to plans for the permanence and continuity of the NFIs, most of the participating countries indicated the necessity to mobilise national and international financial resources, such as from the REDD+ results-based payment mechanism, climate change-related projects or other international sources (such as credits and other donations) in order to ensure their continuity over time. In addition, the integration of other monitoring initiatives into the NFI (such as remote sensing, permanent carbon monitoring plots and assessment of non-wood forest products) is considered necessary, thereby producing updated information (Table 3.3). Other relevant aspects mentioned were the need to mobilise REDD+ institutional resources.

TABLE 3.3

Plans for national forest inventory permanence and continuity per country

Plans	Countries	Number of countries (n = 20)
Resource mobilisation	Belize, Brazil, Colombia, Costa Rica, Dominican Republic, Ecuador, Guatemala, Jamaica, Mexico, Nicaragua, Panama, Peru, Suriname	13
Integration of other monitoring initiatives into the NFI	Belize, Brazil, Colombia, Costa Rica, Dominican Republic, Ecuador, Jamaica, Mexico, Nicaragua, Peru, Puerto Rico, Suriname	12
Improvement of institutional arrangements in the National Forest Monitoring System	Belize, Brazil, Colombia, Costa Rica, Dominican Republic, Ecuador, Guatemala, Jamaica, Nicaragua	9
Integration into institutional annual plans	Belize, Brazil, Colombia, Costa Rica, Guatemala, Jamaica, Nicaragua, Panama	8
Increase of institutional human resources	Belize, Brazil, Colombia, Guatemala, Mexico, Suriname	6
Development of specific legislation	Belize, Colombia, Jamaica, Panama	4
Integration with the national greenhouse gas emission inventories initiative	Brazil	1
The permanence of the NFI is assured	Brazil, Chile, Honduras, Jamaica, Peru, Puerto Rico	6
The permanence of the NFI is currently undetermined	Argentina, El Salvador, Dominican Republic, French Guiana, Suriname, Uruguay	6

Note: NFI: national forest inventory.
Source: Prepared by the authors.

Table 3.3 shows how the following actions are necessary in the medium- and long-term management plans to ensure the permanence of NFIs: improve institutional arrangements in the National Forest Monitoring System for REDD+, integrate NFIs into annual institutional plans, and increase institutional human resources to carry out the NFI activities. A small group of countries (Belize, Colombia, Jamaica and Panama) mentioned the need to develop a regulatory framework and specific legislation to support their continuity. In a third group, there are six countries that have assured the long-term continuity of their NFIs, and six countries that have not ensured their sustainability over time. Finally, only one country mentioned integration with the national greenhouse gas emissions inventory initiative as important for its continuity over time.

Finally, it is important to mention that addressing the institutionalization of NFIs is a process that requires solid planning and continuous improvement to support the necessity and importance of maintaining this activity. The idea is to create a favourable environment in which the entire process – from planning to development to results – may unfold as smoothly and efficiently as possible.

3.3 FINAL CONSIDERATIONS

The analysis of future prospects in the region, in terms of NFIs and forest monitoring, is not a simple task. The homogenisation of the variables presented by each of the countries in this chapter made it necessary to develop a short and simple questionnaire that provided a basis for the discussion, grouping and analysis of these variables.

This analysis shows that in most countries in the region there has been a shift in perspective regarding NFIs, which implies an increasingly systemic vision of the forest ecosystem, incorporating new variables into monitoring. Added to this is the introduction of new desktop and field technologies to optimize human, economic and time resources. There is therefore a clear tendency towards a multipurpose NFI that includes various information sources, which will provide increasingly complete and robust information.

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NEXT CHAPTER

Chapter

CHALLENGES AND OPPORTUNITIES FOR NATIONAL FOREST INVENTORIES

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4.1 INTRODUCTION

The introduction (Chapter 1) highlights the relevance of national forest inventories (NFIs) for decision-making related to forest management, planning and policy. Science and public policy need to work in close collaboration, while paying attention to the role of knowledge (Siclari Bravo, 2020).

This chapter discusses the challenges and opportunities of NFIs in Latin America and the Caribbean (LAC), analysing aspects related to the influence of the institutional framework and different sampling designs, the challenges in providing estimates that can be compared internationally, and the need to improve the transparency and transfer of information (Siclari Bravo, 2020).

4.2 THE INSTITUTIONAL FRAMEWORK, PLANNING AND ORGANIZATION OF NATIONAL FOREST INVENTORIES IN LATIN AMERICA AND THE CARIBBEAN

As concluded from the results of the questionnaire on future prospects for NFIs (Chapter 3), one of the most important factors for ensuring the continuity of NFIs – and one of the most relevant aspects that LAC countries should focus on – is to advance towards their institutionalization. Institutionalization involves ownership and responsibility on the part of the national administration, including aspects such as the existence of legislation that provides NFIs with a solid legal framework, which, in turn, enables access to a guaranteed long-term government budget; it also implies a governance structure with clear roles for the participating entities, and permanently

trained staff with the technical and scientific support of research and training teams (FAO, 2017, 2021). During the work sessions held with countries of the LAC region, the financial sustainability of NFIs was a common challenge for most countries; therefore, the intention is to continue the dialogue to seek solutions that help to secure stable funding resources – primarily from national budgets, but also with the support of international cooperation – while consolidating the institutional framework in each of the countries.

Furthermore, NFIs require detailed planning in order to obtain successful, high-quality measurements. The first step should be to establish institutional arrangements for effective coordination. In Latin America and the Caribbean, most NFIs are led by the forest service, where permanent offices have been established. This condition is critical for achieving long-term sustainability. National forest inventories involve organizing with local governments and decentralized offices, mobilising staff throughout the territory and hiring local staff to facilitate access permits in each of the communities visited and to assist with species identification and data collection. The teams responsible for measurement must be trained to enter the territory and forests safely and to take high-quality measurements. Implementation strategies may vary from country to country depending on funding sources and existing capacities. Throughout the national chapters of this publication, the reader will learn about different NFI implementation strategies.

4.3 INFLUENCE OF METHODOLOGICAL DIFFERENCES ON DATA COMPARABILITY

National forest inventories are national processes, in principle independent of each other, such that in many cases the data provided internationally by different countries are difficult to compare (McRoberts, Tomppo and Næsset, 2010). Previous experiences of harmonization processes that have established common reference definitions – as in the case of the European NFI network (ENFIN) and the Inventory and Monitoring Working Group of the North American Forest Commission (NAFC) – serve as a reference for the LAC region, which seeks reliable, comparable data for planning and decision-making at national, regional and global levels.

National forest inventories in the LAC region have different designs and methodologies as they need to be adapted to multiple circumstances (see Chapter 2). However, to ensure comparability, it is not necessary to set sampling design standards such as sampling grid size (distance between sampling units) or size of sampling units; if NFIs are designed in a statistically robust way, estimates of different indicators can be compared across countries (Vidal *et al.*, 2016a). Moreover, an important point to consider is that standardizing the design would be economically expensive and would lead to a loss of information; among other factors, analysing the evolution of different indicators would not be possible given the lack of continuity with historical data (Tomppo *et al.*, 2010). Therefore, in order to improve comparability, it is essential to have clear documentation and to establish reference definitions that consider all threshold values. For example, to determine volume, the following factors should be defined: how the stem diameter of trees will be measured, the minimum tree sizes to be included in the sample, and the tree compartments to be included (Gschwantner *et al.*, 2019).

The design conditions to be considered in the harmonization process in LAC are discussed below.

4.3.1 NATIONAL FOREST INVENTORIES AND REMOTE SENSING

Forest monitoring can be based on field sampling through NFIs, remote sensing, or a combination of both; the latter provides more complete information that optimizes costs and improves estimates (Lister *et al.*, 2020; Kangas *et al.*, 2019).

National forest inventories are the most important source of field data for countries and, given their relevance, they require a greater commitment of resources to obtain sufficient sampling, especially in large, heterogeneous and highly diverse landscapes. However, NFIs are necessary because, among other reasons, they provide data for the generation of remotely sensed maps. These data are taken from the field, and, at present, many variables cannot be reliably obtained from remotely sensed data, such as soil carbon, species composition and tree regeneration. On the other hand, the use of remote sensing offers advantages that, in addition to cost, include the possibility of updating data more frequently and full national coverage without

issues of inaccessibility (although image quality limitations should be considered, such as areas with persistent cloud cover).

When integrating both sources of information, remote sensing is a key support for NFIs today (McRoberts and Tomppo, 2007; Kangas *et al.*, 2018; Lister *et al.*, 2020). In addition to the use of updated and classified satellite imagery based on national definitions for the production of maps and area estimates (McRoberts and Tomppo, 2007), this integration is also important for providing ancillary information to support planning, estimation and inference (Kangas *et al.*, 2018). Finally, the integration of modern technologies in data collection, such as LiDAR (light detection and ranging) and drones (Henry *et al.*, 2015), can also contribute to improving the efficiency, quantity and quality of information produced by NFIs (Breidenbach *et al.*, 2020)

At present, one of the biggest challenges in LAC is to better integrate NFIs into National Forest Monitoring Systems using remote sensing. As mentioned in Chapter 3, most countries stressed the need for integration with other monitoring initiatives. This lack of integration could imply the need for more resources to produce the country's forest statistics and could cause data discrepancies.

4.3.2 NATIONAL FOREST INVENTORY CYCLES

It is recommended that in the future all countries in the LAC region make periodic or continuous NFIs to update national and international statistics. In LAC NFIs, it is especially difficult to sustain the costs of monitoring to comply with the period of each cycle (see Chapter 2), thus a discussion at international level is timely in order to procure regular funding.

The annualisation of NFIs, understood as the planned division of the total number of sampling units foreseen in the cycle for a proportional measurement in each working year, may be an alternative to obtain annual data that can be adapted to different periods of forest information requirements. The division is made into subsets called panels, which cover the national forest area (McRoberts, 2008). However, this may not be an easy decision for many countries, as it requires stability in the availability of human and financial resources, as well as increased costs for the same sampling intensity. Some countries have already adopted annual panels, such as the United States of America (McRoberts, 2008), the Republic of Korea (Kim *et al.*, 2008), France (Vidal *et al.*, 2007), Costa Rica (Chapter 12), Honduras (Chapter 17) and Peru (Chapter 22). Moreover, it should be considered that annual inventories may partially capture sporadic events (such as storms, forest fires, etc.), although there are special considerations that should be taken into account when interpreting these data and comparing them between countries that are using different sampling systems. If estimates of forest attributes are averaged over the whole cycle based on annual measurements, each annual average estimate will contain some plots that are affected by the event and others that are unaffected (Patterson and Reams, 2005). At the end of the cycle, the data will reflect the impact of the event, but at different times; that is, the impact of the event is diminished in the year it occurs, but its impact is prolonged (Coulston *et al.*, 2020).

In order to make a simple estimate of indicators, one could consider a five-year cycle of LAC NFIs (as in most LAC countries) linked to the reporting dates of the Food and Agriculture Organization of the United Nations (FAO) Global Forest Resources Assessment (FRA) or greenhouse gas inventories (GHGI). However, there are other options when robust NFI data are available, such as data modelling to project the data to the year for which information is required (Kangas *et al.*, 2019). Indeed, as Kangas *et al.* (2019) point out, both sampling design-based data inference and data modelling are currently needed in order to meet all information needs at different temporal and spatial scales. Establishing and defining bias, as well as its implications for all data estimates used in policymaking, is also relevant and represents a topical challenge in the region.

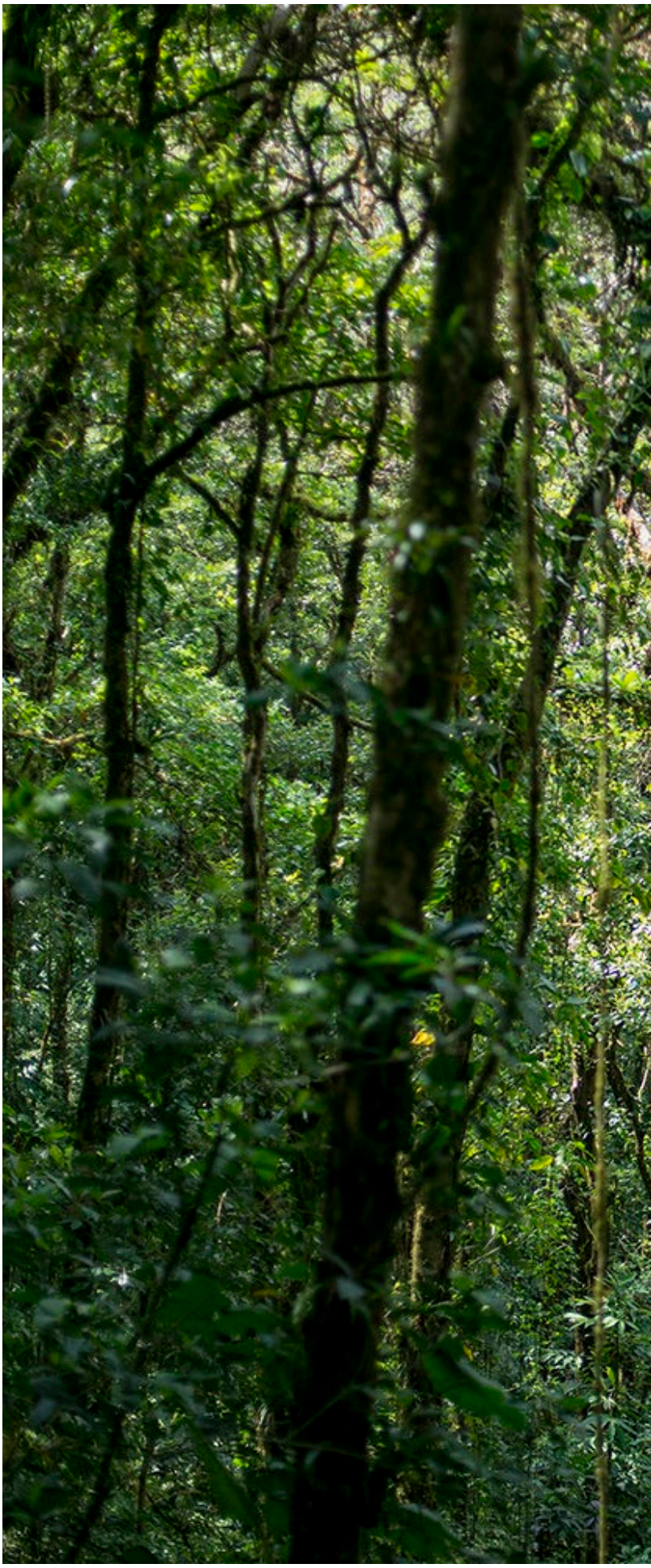
4.3.3 SAMPLING DESIGN

The size of the field sampling unit is diverse in LAC NFIs, considering that it is defined according to forest characteristics, information needs and implementation costs. In general, larger sampling units are used in heterogeneous areas and in open (low density) forests (McRoberts, Tomppo and Czaplewski, 1992). In addition, differences between countries in sample size and design can also be found within the same country. This is the case in Peru, which has two types of sampling units: i) clusters of 10 circular plots are used for highland tropical rainforest, coastal highland and hydromorphic zone subpopulations, and ii) 7 rectangular plots are used for the lowland tropical rainforest subpopulation (see Chapter 22).

There has been a clear trend in recent years towards the use of clusters in LAC (see Chapter 2), with the aim to form a sampling unit that better captures variability at the sampling site (compared to a single plot of equal or larger area). Such sampling should be undertaken when the time and resource savings in the measurement process – within a sampling unit with multiple plots of a given size at a specific distance – exceed those of a large plot (McRoberts, Tomppo and Czaplewski, 2015).

Regardless of the plot design chosen by a country for implementation in its NFI, a change in design from one NFI to the next should be seriously considered and planned. The benefits of an innovative design, such as improved efficiencies, increased accuracy and precision of the estimate, harmonization with international standards, etc., must be weighed against the potential loss of the continuity of data to analyse historical trends; this can occur either because of an inherent incompatibility between the old and new designs, or due to greater uncertainty in distinguishing a true change in the resource from a variation introduced by the change in methodology.

In any case, the existence of different sampling unit sizes and designs is not an obstacle to the harmonization of estimates; nevertheless, the influence of this design variability on each of the different variables must be analysed.



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4.4 CHALLENGES TO PROVIDING HARMONIZED DATA IN THE LATIN AMERICAN AND CARIBBEAN REGION

There are challenges to harmonization within and between countries in the Latin American and Caribbean region. Despite significant advances in recent years, there is a need to improve communication, cooperation and technical discussion on a regular basis. International collaborative research aimed at data harmonization is required as part of the process.

In many cases, estimates of forest area in LAC are based solely on remotely sensed data, while in other cases these estimates combine both sources. It is particularly noteworthy that the minimum tree cover used to define a forest varies between NFIs. In the FAO definition of forest, the tree canopy cover should be 10 percent (FAO, 2020), but several countries consider higher values, generally in the range of 25 percent to 30 percent (Chapter 2). This raises the need to work specifically on improving the comparability of this highly relevant data in the region and on combining remote sensing and forest inventory techniques.

Dasometric variables such as height and diameter are measured in all NFIs (Chapter 2), although there are differences in their definition and in the subsequent estimation of related indicators (such as volume or biomass). Definitions differ due to the thresholds considered as the minimum diameter or height to measure a tree; in volume or biomass estimations, the equations used may take into account different tree compartments (branches, bark, stump, among others) (Gschwandtner *et al.*, 2019). Therefore, this book discusses for the first time the definitions and thresholds used for three key variables: forest land area, volume and above-ground biomass.

Three aspects highlighted by LAC NFI national experts that would be of great interest to improve the comparability of data are as follows:

- Develop a classification of forest types for LAC, based on FRA terms and definitions and building on the experiences of harmonizing land use and land cover classifications in countries such as Guatemala (Saput *et al.*, forthcoming) and Costa Rica (CENIGA, 2020).
- Use the same data model and nomenclature for plant species in LAC, for instance, Plinian Core (https://github.com/tdwg/PlinianCore).
- Generate a database with recommended allometric equations per species or taxonomic group, which could be based on existing platforms such as FAO's GlobAllomeTree (www.globallometree.org/).

4.5 INCREASING INFORMATION REQUIREMENTS AND THE POTENTIAL OF NATIONAL FOREST INVENTORIES

New demands from society and the international forest agenda contribute to the incorporation of new variables and more rigorous assessments on issues such as biodiversity (including the collection of data on genetic material), non-wood forest products, soils and the local value of forests for people. This information is being collected by some countries, although the inclusion of new field variables needs to be carefully evaluated from the point of view of the amount of time invested (and the associated cost), as well as the training of technicians to avoid assessment errors (Ringvall *et al.*, 2005).

The considerable number of variables measured, coupled with the credibility and suitability of the information produced (such as a statistically based sampling system, defined field protocols, trained field teams and quality control), enhance the application of NFIs as a source of information for various national and international reports (Vidal *et al.*, 2016b). For example, in the international context, NFIs are very important for estimating greenhouse gas emissions from the forest sector to be reported in reference levels for the Reducing Emissions from Deforestation and Forest Degradation (REDD+) mechanism and for reporting progress or results in National Communications (NCs), Biennial Update Reports or Biennial Transparency Reports (FAO, 2018, 2020).

The use of NFIs can also be extended to other potential requirements, for instance, those related to biodiversity monitoring (Chirici *et al.*, 2012) or forest restoration (Ramírez and Morales, forthcoming).

4.6 NEED TO IMPROVE THE TRANSFER OF INFORMATION

Proper data management of NFIs is essential to establish a clear pathway between planners and decision-makers of countries in the region. Data entry, analysis and reporting systems, such as Open Foris and Arena, are examples that can be followed by LAC countries and their further development could help emerging NFIs. A complete harmonization of LAC NFI indicators to allow for comparability would support regional decision-making.

Although data policies in different NFIs vary, a key aspect to encourage and maximise the use of data collected by NFIs is to promote the transparency of forest data (see Chapter 5).

It is also crucial to communicate comprehensive forest information to society through accessible databases, comprehensive reports and publications aimed at different target groups (managers, policymakers, etc.) (Alberdi *et al.*, 2017; FAO, 2017).

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Chapter

TOWARDS TRANSPARENT AND OPEN DATA IN NATIONAL FOREST INVENTORIES

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5.1 INTRODUCTION

Open forest data is critical for the monitoring of natural resources, tailored programming and policy interventions, the evaluation of their impacts, as well as the advancement of science through novel research. It is also critical for tracking progress on the Sustainable Development Goals of the 2030 Agenda and the Paris Agreement commitments. In fact, transparency is one of the key concepts in the Paris Agreement and a prerequisite for gaining access to the performance-based payments in the context of Reducing Emissions from Deforestation and Forest Degradation (REDD+) and other results-based payment schemes.

Increased transparency of forest-related data is also a catalyst for higher levels of ambition for the role of forests in the sustainable production of forest-based good and services (CDP, 2014), climate change mitigation and adaptation (Liang and Gamarra, 2020) and biodiversity conservation (Kormos *et al.*, 2017).

While transparent data and reporting have already been successfully demonstrated by more than 50 countries in the context of reporting forest reference emission levels to the United Nations Framework Convention on Climate Change (FAO, 2020; Yanai *et al.*, 2020), efforts towards forest data transparency must continue to be strengthened. Robust and transparent data collection, analysis and dissemination are central for international reporting, including climate change, biodiversity and forest-related forums.

In the last decade, the REDD+ framework has contributed to pushing forward the development of national forest inventories (NFIs), leading to increased transparency in National Forest Monitoring Systems (NFMS). Bypassing previous approaches to reporting expert opinion-based estimates, more and more countries have incentivised scientific approaches in planning, implementing and analysis of NFIs (Romijn *et al.*, 2012; Kleinn, 2017). Latin America has taken positive steps in this direction, proving that transparent data help governance and decision-making. Today, forest data users need much more detailed information – metadata – on the data they access, as well as information that is more local and less uncertain (Romijn *et al.*, 2018). Regional initiatives aiming to share NFI designs, processes and institutional mechanisms will help in unifying approaches to global information needs. Latin America and the Caribbean's recent South-South cooperation initiative is paving the way towards a harmonized regional approach to open policies in forest data and governance. The next sections will explain the efforts being undertaken towards transparent and open forest data.

5.2 TRANSPARENT AND OPEN FOREST DATA PRINCIPLES

The recent *Voluntary Guidelines on National Forest Monitoring* (VGNFM) provide principles, elements and best practices for the establishment and implementation of an NFMS (FAO, 2017). A strong NFMS is built on an NFI or a combination of an NFI and a Satellite Land Monitoring System, and it provides information about the extent, distribution, composition and condition of forests and woodlands, as well as the changes taking place in these areas through time. Two principles of the VGNFM that provide guidance on transparency and open data in the forest sector are "Credibility through transparency and quality" and "A well-defined data and information sharing policy."

Credibility through transparency and quality

The results of any NFMS must be scientifically defensible; therefore, each methodological and organizational step needs to be documented and justified in a transparent way. The information products generated by the NFMS should allow any user to understand the processes of design, data collection and analysis in order to comprehend the quality and credibility of the reported results. Achieving this particular principle will depend on the long-term ability of the responsible organizations to institutionalize the NFMS process and to document, store and disseminate related data, metadata and information.

A well-defined data and information sharing policy

Data, metadata and information produced by NFMS are of interest to many different stakeholders. To inform policy formulation and decision-making, as well as to advance science, they should be disseminated as widely as possible with varying levels of detail. Thus, a clear data sharing policy needs to be in place to which national and international users can refer. Implementing a long-term data sharing policy also means that long-term data storage and management need to be secured.

5.3 TYPES OF DATA

Forest-related data are categorised into two types: survey-based and census data.

- **Survey-based data** are collected through a random selection of individuals or units in a sample from an initial enumeration of all the elements of a population (for instance, all tree-populated areas in a given country). These data can be:
  - *In situ* forest data: survey data collected through direct measurement in the location where the population exists (Liang and Gamarra, 2020). Within this category, reporting practice shows the level of aggregation of the data – the spatial or categorical scale at which the data are summarised:

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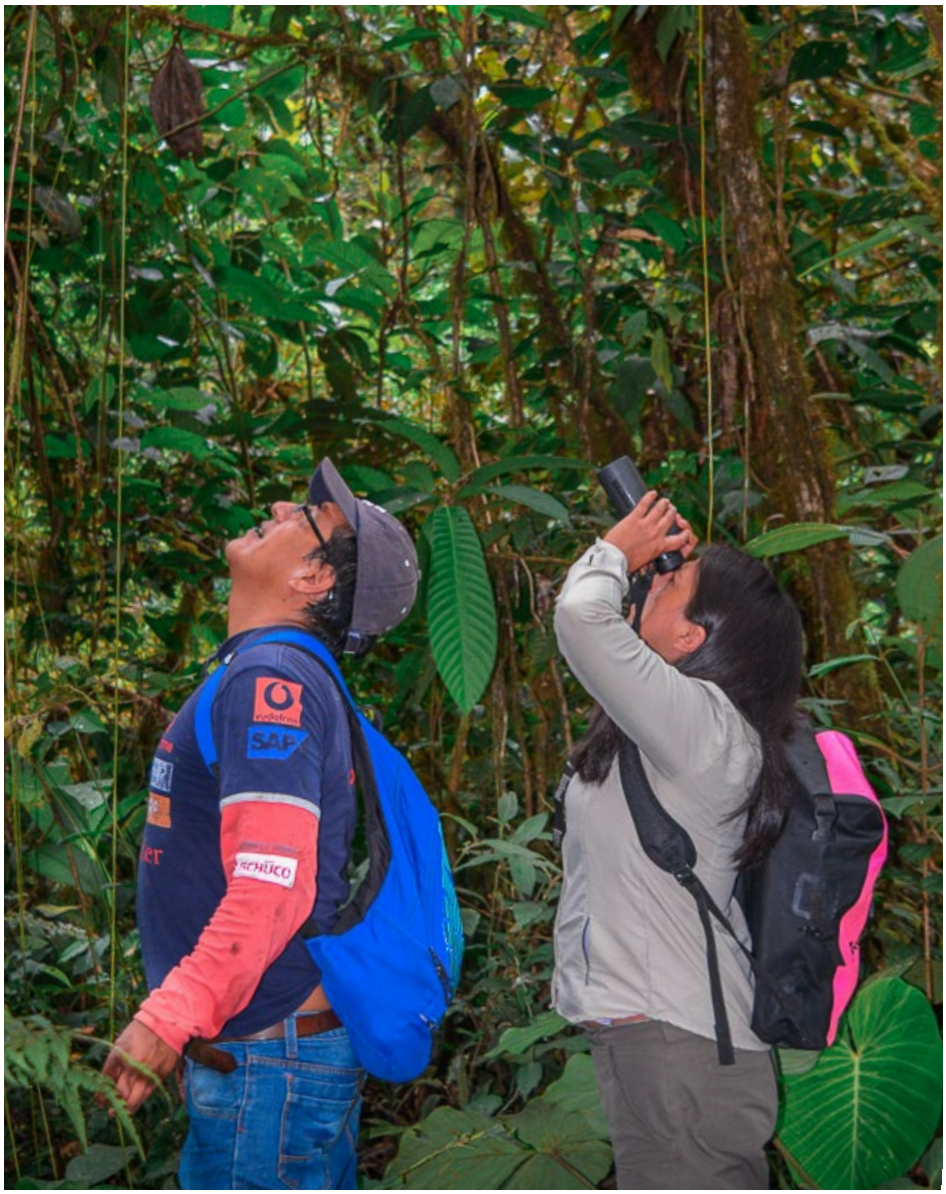

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- tree- or individual-level data: data usually defined as "microdata"; they provide information on individual entities such as trees, households, business enterprises, facilities or farms;
- plot-level data: higher-level data acquired by aggregating microdata (e.g. individual tree-level measurements) at the level of the basic unit of sampling design and analysis: the plot;
- domain-based data: aggregated data used in reports describing total or mean estimates by certain categories or domains (e.g. forest type, administrative unit, diameter class).

◊ *Ex situ* forest data: data collected without a physical visit to the sampling site. These data are collected through the analysis of geospatial data (e.g. remote sensing data compiled through sampling).

- **Full-coverage or census data:** census data (data compilations of all elements in a population) collect data on human populations to describe social, economic and demographic conditions. In the forest sector, they are collected only for very specific purposes (for example, censuses of urban trees). More generally, wall-to-wall geospatial data (such as maps) combining location information, attribute information (the characteristics of the object, event, or phenomena concerned), and often temporal information (the time or life span at which the location and attributes exist) are widespread and openly available through many platforms (Stock and Guesgen, 2016).

5.4 A CALL FOR SHARING FOREST DATA

To meet the open access principles, data should be available to all users and not impeded by any financial, organizational, legal or technical barriers (Research Council of Lithuania, 2016). Today, the most common ways to disseminate open data are through online repositories and downloads to digital storage media.

A fundamental tenet of online repositories involves the preparation of metadata following internationally agreed standards. Metadata is documentation that transforms data from a stream of numbers and characters into information (Lin *et al.*, 2008). It describes concepts such as scale, scope, measurement units, codes used, survey design, quality control procedures and initial objectives of the study (Pelkki and Arthaud, 2000). In its simple form, metadata should aim to establish a common set of questions that guides a data user to reproduce reporting results following FAIR (findable, accessible, interoperable, reusable) guiding principles (Wilkinson *et al.*, 2016). Currently, a metadata standard is lacking for forest-related repositories, although international efforts have been made towards data standardization (Köhl, Traub and Päivinen, 2000) and methodological harmonization for reporting (Winter *et al.*, 2008; Tomppo and Schadauer, 2012).

One established related standard is the Ecological Metadata Language (EML) (Fegraus *et al.*, 2005). It contains features that are lacking in other more general metadata protocols, such as basic specific information on geographic boundaries or taxonomic information. However, metadata on forestry and natural resources often contains information on socioeconomic surveys, which are studies not fully covered by EML. Hence, a more inclusive approach can be supported by other metadata protocols that are focused on survey information that addresses a wide variety of populations (whether animal, plant or human). The World Bank adopted the Data Documentation Initiative (DDI) for that purpose (Ryssevik, 2001). Initially, it was designed to cover data for the social sciences (Vardigan *et al.*, 2008); however, it is comprehensive enough to cover most of the information typically contained in NFIs and was also adopted by the Food and Agriculture Microdata (FAM) catalogue of the Food and Agriculture Organization of the United Nations (FAO).

In the end, any agreement on metadata standards needs to focus attention on the end data users and remain loyal to open data principles, while respecting countries' national circumstances and their privacy obligations, which in the case of forest-related data go beyond those typically used by national or international statistics organizations. Some examples include sensitive taxonomic information like species with protection status under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and their specific geographic locations. While academic objectives should aim to open all data as much as possible, international agreements should respect country-based constraints. A trade-off for data disclosure should be considered through an honest discussion among all stakeholders involved.

Forest-related information remains scattered across many platforms. Furthermore, issues related to data confidentiality are a major contributor to initial mistrust regarding data sharing (Gewin, 2016). A survey commissioned by the European Open Science Monitor and conducted by the Elsevier–Leiden University consortium has shown that potential users are eager to respond positively to data sharing offers by others. By contrast, they are reluctant to share their own data (Wouters and Haak, 2017), raising once again the paradox of a decision trade-off between risk and data utility that may force data users and data providers into a tragedy of the commons game (Houtkoop *et al.*, 2018).

Because of this, some existing microdata platforms, such as the Global Forest Biodiversity Initiative (https://gfbinitiative.net/) (Liang *et al.*, 2016), compile and share global field data for academic research and need strict rules on confidentiality and user access conditions. Nevertheless, there is increasing evidence that the forestry community is becoming more positive about releasing its data in an open manner and at a higher level of detail than was previously done (see, for example, Borghetti and Chirici, 2016; Stanke *et al.*, 2020). This trend was also confirmed by a recent survey conducted by FAO among the Global Forest Resources Assessment (FRA) National Correspondents (FAO, 2019). The results indicate that 63 countries consider it useful to have a global online platform for storing national forest inventory data. They also suggest that 34 countries that expect to have new data available within the coming years are interested in publishing them as open data.

To fulfil its mandate to collect, analyse, interpret and disseminate food- and agriculture-related data, as well as to implement the Organization's Open Data Policy, FAO had developed open access solutions for the collection, analysis and dissemination of forest-related data. These solutions include the following:

- Open Foris: a set of free and open-source tools to facilitate flexible and efficient data collection, analysis and reporting (http://openforis.org/).
- Global Forest Resources Assessment Platform: an interactive online application for easy access to national-level data and metadata reported to the FRA process by countries and territories (https://fra-data.fao.org/).
- Hand-in-Hand geospatial platform for transparent sharing of cross-sectoral geospatial data across agriculture, fisheries and forestry. Visualisation of geospatial forest-related data is available at national level (www.fao.org/hand-in-hand/en/).
- Food and Agriculture Microdata Catalogue: provides an inventory of datasets collected through farm and household surveys, which contain information related to agriculture, food security and nutrition, thereby contributing to increased standardization, accessibility and data usage (https://microdata.fao.org/index.php/catalog/central/about).

5.5 CONCLUSIONS

In the midst of the Big Data era, forest information is no outlier to calls for increased access by a multitude of actors, from scientists to citizens and decision-makers to forest users. Sharing large amounts of forest data will not only expand knowledge of our precious natural resources, but will also increase synergies between global stakeholders. As a result of this vast collaborative exercise, we can expect that decision-makers will be provided with more precise tools with the potential to achieve the Sustainable Development Goals within a shorter time frame. Swift action is required when confronted with impending climate emergencies.

The actions implemented will require efforts to provide microdata, agreements on international standards for forest metadata and institutional will. Countries will then be able to develop informed forest and land use policies with proven knowledge and up-to-date, reliable, transparent and accessible information, basing their policies on the following key aspects:

- Improved data availability and accessibility combined with transparency could catalyse more collaborative solutions to help meet national and international agendas.
- Integrated and frequent forest data are likely to enhance public engagement and collaboration on relevant solutions for forests.
- Open, transparent and reliable forest data can also encourage private investment, which is urgently needed to trigger overall societal involvement and new transitions in forest and land management that can help buffer the deleterious effects of business-as-usual scenarios, as well as improve livelihoods.
- Accurate and reliable forest data created from public funds need to be open and accessible to the public.
- Overcoming obstacles to sharing forest data, such as the concern of inadequate use of the data and lack of intellectual property recognition, is fundamental to unlocking greater availability of and access to forest data.

A natural, higher-level consequence of open data is the forging of paths towards regional harmonization to facilitate transparency and comparability. Countries in Latin America and the Caribbean are demonstrating institutional will in this direction.

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NATIONAL FOREST INVENTORIES OF LATIN AMERICA AND THE CARIBBEAN

Towards the harmonization of forest information

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Chapter 6

ARGENTINA

NATIONAL NATIVE FOREST INVENTORY OF ARGENTINA

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6.1 HISTORICAL OVERVIEW OF NATIONAL FOREST INVENTORIES

The First National Native Forest Inventory (FNNFI) of Argentina started in 1998, as part of the Native Forests and Protected Areas Project (IBRD 4085-AR), agreed between the national government and the International Bank for Reconstruction and Development. The national territory was organized into six forest regions: Missionary Forest, Bolivian Tucuman Forest, Andean Patagonian Forest, Chaqueño Park, Espinal and Monte. In every region, the areas of native forest were identified through remote sensing techniques and, except in the Monte region, a field inventory was undertaken to collect dasometric data. The sampling procedure was systematic with spatial distribution based on a square grid that varied according to forest regions, that is, the selection of sampling units was not proportional to the population (Table 6.1). The results were divided into classes according to the land classification definitions proposed by the Food and Agriculture Organization of the United Nations (FAO) through the Global Forest Resources Assessment (FRA) of the year 2000 (FAO, 2000), adapted to the characteristics and particularities of Argentina. This allowed the country to have, for the first time, reliable national data on the distribution, characteristics and state of native forests, providing the authorities with the necessary information for the formulation of policies on the use of forest resources.

The National Law No. 26331 on Minimum Standards for the Environmental Protection of Native Forests was enacted in 2007. This law establishes a minimum environmental protection budget for the enrichment, restoration, conservation, use and sustainable management of native forests and the environmental services they provide to society (Argentine, 2007). Its Regulatory Decree No. 91/2009, in Chapter 4, Article 11, states the following: "to update the National Native Forest Inventory, at most every five (5) years, providing the necessary financing mechanisms" (Argentine, 2009). In this new context, the Ministry of the Environment and Sustainable Development (MAyDS) as the national implementing agency, through the National Forest Directorate (DNB), is responsible for maintaining updated information on the area covered by native forests and their state of conservation.

The Second National Native Forest Inventory (SNNFI) was prepared as a result of these developments, to serve as a national strategic tool for the development of public policies related to the conservation and sustainable management of native forests, in compliance with the prevailing national legislation. The National Native Forest Inventory (NNFI) is designed to generate the necessary data to follow up on

Argentina's international commitments on climate change. The formulation and agreements on the design of field data collection for the SNNFI were based technically on the experience of the FNNFI, the information published in provincial, regional and other countries' forest inventories, and the new definition of native forest set out in Law No. 26331. In parallel, the DNB carries out satellite monitoring and mapping of native forests, which is complemented with the NNFI field information, forming the National Native Forest Monitoring System; the DNB has also assessed the loss of native forest since 2006 in order to contribute to verifying compliance with the aforementioned law (UMSEF, 2019). In the FNNFI, 473 sampling units were installed in the field, without being regarded as permanent. In the SNNFI, the points of the national grid, resulting from superimposing the grid with the country's land area, were considered as potential sampling points (PSP). The sampling points (SP) were later identified by intersecting the PSP with the area of native forest in all of Argentina's forest regions. Finally, sampling units (SU) were identified at the geographical points where measurements were actually taken in the field and the sector was thus identified as permanent (Table 6.1).

As mentioned above, the design of the SNNFI is based on the experience of the FNNFI, as well as forest inventories at provincial, regional and national level and in other countries. For the purpose of the SNNFI, the national territory has been organized into seven forest regions (Figure 6.1): Paranaense Forest (formerly Missionary Forest), or SPA; Yungas (formerly Tucuman-Bolivian Forest), or YUN; Andean Patagonian Forest, or BAP; Chaqueño Park, or PCH; Espinal, or ESP; Monte, or MON; and Parana Deltas and Islands, or DIP. There are two substantial differences between the FNNFI and SNNFI. In the latter, no pre-stratification was carried out, since post-stratification techniques were used, and the sampling units are permanent plots, thus providing the basis for a periodic or continuous inventory.

In March 2021, reports were officially submitted from the seven regions with their respective results; these are considered to be an initial review, with the exception of the BAP forest region which is in its second review (the reports can be accessed through the SNNFI website: www.argentina.gob.ar/ambiente/bosques/segundo-inventario-nacional-bosques-nativos). For this reason, the results of the BAP region are presented in this chapter.

The implementation of SNNFI was made possible through a notable interinstitutional and interjurisdictional effort and various funding sources: Native Forests and Community Project (IBRD 8493), National Programme for the Protection of Native Forests (Law No. 26331), United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (UN-REDD) and the Forest Carbon Partnership Facility (FCPF).

TABLE 6.1

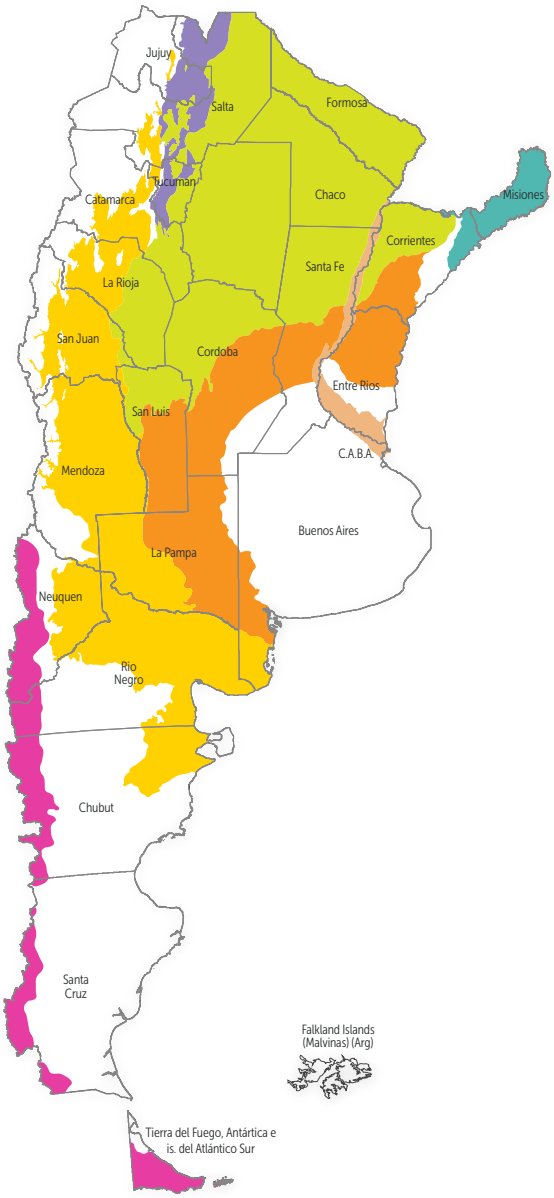
Historical overview of the National Native Forest Inventories of Argentina

Inventory cycle	Implementation period	Scale	Sampling design	Potential sampling points (PSP), sampling points (SP), sampling units (SU)
FNNFI	1998–2006	National	Systematic pre-stratified, with selection non-proportional to the population and for each forest region or pre-stratum. The SU size between forest regions ranged from 0.15 ha to 0.8 ha and were of rectangular/circular shape.	PSP: no data
				SP: no data
				SU: 473
SNNFI	2015–2021	National	Systematic with a selection proportional to the population, i.e. a single national grid with random starting point. Sampling units were of 0.1 ha in size and concentric circular shape for all forest regions.	PSP: 27 895
				SP: 4 158
				SU: 3 796

Source: Prepared by the authors.

FIGURE 6.1

Forest regions of Argentina (South American mainland)



LEGEND

Forest regions

- Chaqueño Park
- Paranaense Forest
- Andean Patagonian Forest
- Yungas
- Paraná Deltas and Islands
- Espinal
- Monte
- Non-forest

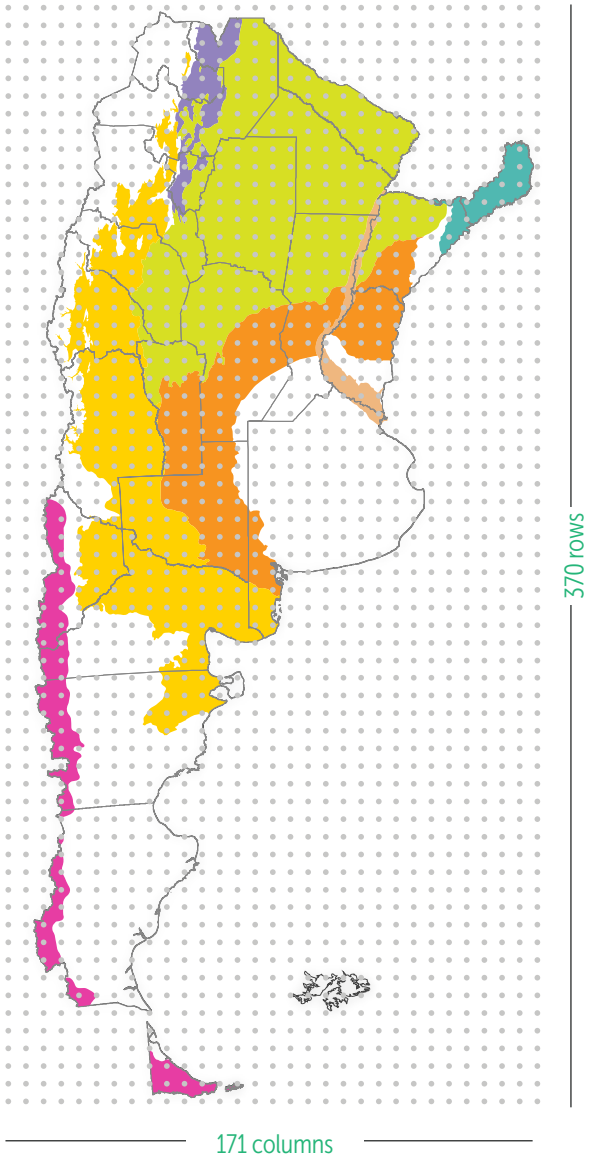
The boundaries shown and the names and designations used on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any countries, territories, cities, areas, authorities, or delimitation of their frontiers or boundaries. Dotted lines on maps represent approximate boundaries for which there may not yet be full agreement.

A dispute exists between the Governments of Argentina and the United Kingdom of Great Britain and Northern Ireland concerning sovereignty over the Falkland Islands (Islas Malvinas).

Source: **UMSEF (Management Unit of the Forest Assessment System)**. 2019. *Monitoreo de la superficie de bosque nativo de la República Argentina. Regiones forestales Bosque Andino Patagónico, Espinal, Monte, Parque Chaqueño, Selva Paranaense y Yungas.* Buenos Aires, Ministry of the Environment and Sustainable Development.

FIGURE 6.2

Grid used in the Second National Native Forest Inventory



LEGEND

Forest regions

- Chaqueño Park
- Paranaense Forest
- Andean Patagonian Forest
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The boundaries shown and the names and designations used on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any countries, territories, cities, areas, authorities, or delimitation of their frontiers or boundaries. Dotted lines on maps represent approximate boundaries for which there may not yet be full agreement.

A dispute exists between the Governments of Argentina and the United Kingdom of Great Britain and Northern Ireland concerning sovereignty over the Falkland Islands (Islas Malvinas).

Source: **SAyDS. 2019.** Segundo Inventario Nacional de Bosques Nativos (INBN2): Manual de campo. Buenos Aires.

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6.2 TERMS AND DEFINITIONS RELEVANT TO THE IMPLEMENTATION OF THE NATIONAL NATIVE FOREST INVENTORY

The classification proposed by FAO in the FRA 2000, comprising "forest", "other wooded land" and "other land" classes, was adapted to the characteristics and specific features of Argentina and used in the structure and updates of the FNNFI (SAyDS, 2005a; UMSEF, 2019).

Today, the official definition of native forest – established by Law No. 26331 (Argentine, 2007), its Regulatory Decree No. 91/2009 (Argentine, 2009) and Resolution No. 230/2012 of the Federal Environmental Council (Argentine, 2012) – includes all natural forest ecosystems at different stages of development, of primary or secondary origin, with a tree cover of native species greater than or equal to 20 percent and with trees reaching a minimum height of 3 metres (m), including palm groves. Table 6.2 shows the adaptation of the SNNFI definitions and their relationship with the current definition of native forests. Thus, native forest to be inventoried (field measurement area) comprises the classes of forest land and types 3 and 5 of other wooded land. By contrast, forests planted with native and/or exotic species are subject to study and monitoring by the Ministry of Agriculture, Livestock and Fisheries under the coordination of the National Directorate of Industrial Forestry Development, through the National Inventory of Forest Plantations, and are not included in this report.

6.3 SAMPLING DESIGN

The SNNFI design is based on systematic sampling that is proportional to the population, that is, based on a single grid of equidistant points every 10 kilometres (km) extending over the entire continental territory of Argentina, in such a way that the number of samples is proportional to the size of the seven forest regions, which correspond statistically to subpopulations. Measurements were made in the subpopulations or forest regions shown in Figure 6.1. Although it was part of the national sample, no measurements were made in the non-forest area. The grid was developed starting from the country coverage of the GIS-250 (geographic information system with a data capture scale of

1:250 000) of the National Geographic Institute (Instituto Geográfico Nacional – IGN, according to its acronym in Spanish) in the Gauss-Krüger cartographic projection system, band 4 and Datum WGS84 from a randomly generated point. The resulting grid is composed of 171 columns and 370 rows of points with geographic coordinates and each point is identified with a specific code (Figure 6.2).

In the first phase, each PSP is analysed using Collect Earth from Open Foris software to assess whether it coincides with an area to be inventoried and offers viable accessible conditions to become an SP. In a second phase an SU or plot is installed in the SPs of forest to be inventoried (Table 6.3). The total area of each forest region, the number and distribution of SUs, and the total number of PSPs are provided in Table 6.4.

TABLE 6.2

Summary of definitions used in the National Native Forest Inventory

Term	Definition	Variables and thresholds
Forest land (FL)	Land comprising a natural ecosystem with a tree cover of native species greater than or equal to 20 percent with trees reaching a minimum height of 7 m. The forest land class is included in the definition of native forest in Law No. 26331.	Minimum surface: 0.5 ha Canopy: ≥ 20% Minimum tree height: 7 m Minimum width: undefined Exceptions in field data collection: windbreaks, shelterbelts, corridors and tree patches with an area of less than 1 ha are excluded from field sampling
Other wooded land (OWL)	Land which forms a natural ecosystem with: – a tree cover of native species between 5 percent and 20 percent with trees reaching a minimum height of 7 m (OWL1); – tree cover of native species greater than or equal to 20 percent, with trees less than 3 m tall (OWL2); – a tree cover of native species greater than or equal to 20 percent, with trees between 3 m and 7 m in height (OWL3); or – at least 20 percent shrub cover of native species, with shrubs at least 0.5 m in height (OWL4). Palm groves (OWL5) and sugar cane plantations (OWL6) are included. Classes OWL3 and OWL5 are included in the definition of native forest in Law No. 26331.	Minimum surface: 0.5 ha Canopy: ≥ 20% Minimum tree height: 3 m Minimum width: undefined Exceptions in the field data collection: windbreaks, shelterbelts corridors and tree patches with an area of less than 1 ha are excluded from field sampling
Other land (OL)	Land not classified as forest land or other wooded land including grassland, crops, hydrophilic herbaceous vegetation, forest plantations, water bodies, saltwater marshes, areas with no vegetation, urban areas and infrastructure.	
Volume	Total volume (m^3): volume of living trees, from 5 cm or 10 cm diameter at breast height (DBH) depending on the forest region, including bark.	Minimum diameter (DBH at 1.3 m) ≥ 5 cm or diameter at the base (DAB at 10 cm) ≥ 10 cm for Monte, Chaqueño Park, Espinal, and Paraná Deltas and Islands regions; and DBH ≥ 10 cm for Andean Patagonian Forest, Paranaense Forest, and Yungas. Inclusion/exclusion of stump: stump excluded and calculated separately. Stump height is considered to be less than or equal to 1.3 m. Minimum stem top diameter: undefined. The fork of the stem or the beginning of the crown of the tree is considered. Total height: from the base to the top of the crown. Stem height (commercial): from the base to the first branch or fork. The fork of the stem or the beginning of the crown of the individual tree is considered. Groups of species: all tree species identified in the field and sample collection.

TABLE 6.2 (CONTINUED)

Term	Definition	Variables and thresholds
Biomass	Above-ground biomass: currently undefined Below-ground biomass: currently undefined	Above-ground biomass: not included Below-ground biomass: not included
Dead organic matter	Fallen woody material: all small twigs, branches and stems on the ground or accumulated up to 2 m in height, provided that they are detached from their original source. Dead trees: dead standing trees. Stumps (felling): stumps found in the plot with a height lower than or equal to 1.3 m; if the height is greater, it corresponds to a dead standing tree. Leaf litter: not measured	Recorded on the north-south transect of the plot using the intersection method, taking into account its diameter at the point where it intersects the measurement line: – thin: diameter ≤ 2.5 cm – medium: diameter > 2.5 cm and ≤ 7.5 cm – thick: diameter ≥ 7.5 cm Evaluation of the state of the material: bark attached, bark cracked, without bark and partially buried in the ground. The DBH of the stems and the total height of the dead tree are determined. Height ≤ 1.3 m
Soil organic carbon	Currently undefined	

Note: For communication purposes, forest is commonly understood as those areas corresponding to the forest land class. However, some forest areas were defined as non-inventoried and were included in the other forest land class. Over time, this narrow definition was modified by the enactment of Law No. 26331, in which palm groves are also considered native forests. The minimum thresholds of surface, height and crown cover that determine the consideration of a wooded environment as native forest are 0.5 ha of continuous surface, 3 m minimum height and 20 percent minimum crown cover. This definition posed an important challenge for the National Native Forest Monitoring System, as the thresholds established for each class category did not fully coincide with those that had been in place since the First National Native Forest Inventory. For this reason, progress was made in the differentiation of classes for the Second National Native Forest Inventory, wherein forest implies more than forest land and also includes OWL3 and OWL5. It should also be clarified that these are native forests; none of these classes include plantations, which are within the class "other land". Although the definition of forest specifies a minimum area of 0.5 ha, for operational reasons the collection of field data was carried out in forest patches with an area greater than 1 ha. This does not imply that patches between 0.5 ha and 1 ha are excluded from the rights and obligations of Law No. 26331 on Minimum Standards for the Environmental Protection of Native Forests.

Source: Prepared by the authors with data from **Argentine (the Republic of)**. *Law No. 26331 on Minimum Standards for the Environmental Protection of Native Forests*, 2007.

TABLE 6.3

Sampling design characteristics: country level

Name of the region	Native forest area (approximate national total, 1 000 ha)	Potential sampling points (national grid)	Sampling points (forest to be inventoried)	Sampling units installed
Total	**46 866.17**	**17 426**	**4 158**	**3 796**
Paranaense Forest (SPA)	1 545.87	403	167	165
Yungas (YUN)	3 678.74	553	350	296
Andean Patagonian Forest (BAP)	3 241.00	1 234	244	230
Monte (MON)	779.42	5 059	103	80
Espinal (ESP)	5 622.53	3 126	261	253
Chaqueño Park (PCH)	31 945.13	6 701	3 015	2 754
Paraná Deltas and Islands (DIP)	73.47	350	18	18

Source: Prepared by the authors.

The total native forest area of the country (Table 6.4) is a preliminary value derived from regional estimates made through the use of remote sensing tools and geographic information systems, using as a baseline the 2006 update of the FNNFI cartography, available in SAyDS (2005a) and MAyDS (2020a).

In addition, the subsequent native forest monitoring available in Mohr-Bell *et al.* (2019) and SAyDS (2019) and the mapping of the Monte forest region completed in 2019 (report forthcoming) were taken into account.

TABLE 6.4

Area in hectares of the seven forest regions and sampling units

Name of the region	Total land area (1 000 ha)	Number of sampling units			Total number of potential sampling points
		Forest	Other wooded land	Other land	
Paranaense Forest (SPA)	4 551.85	157	8	0	403
Monte (MON)	61 664.43	28	71	0	5 059
Yungas (YUN)	6 044.55	295	0	0	553
Paraná Deltas and Islands (DIP)	4 196.08	16	2	0	350
Espinal (ESP)	37 965.36	195	58	0	3 126
Chaqueño Park (PCH)	75 903.41	1841	911	2	6 701
Andean Patagonian Forest (BAP)	17 416.14	191	39	0	1 234
Non-forest	65 957.18	-	-	-	10 469
Total	**273 699.00**	**2 723**	**1 089**	**2**	**27 895**

Source: Prepared by the authors.

6.4 SAMPLING UNIT DESIGN

The SU or plot is composed of two circular and concentric subplots, designated with the letters A and B, to capture the biggest and smallest trees, respectively; and four circular subplots labelled with the letter C, positioned in a cross for the evaluation of the regeneration of woody species (Figure 6.3). During the installation of the SU, a metal stake is driven into the ground and reference individuals are marked to facilitate the identification of the permanent plot, thus allowing for the future monitoring and detection of changes within the plot.

Subplot A has a surface area of 1 000 square metres (m²), with a radius of 17.8 m. Biometric data, site characteristics and signs of anthropogenic interventions are assessed here (Table 6.5). Subplot B, where biometric data of smaller trees are assessed, measures 255 m², with a radius of 9 m (Table 6.5). Subplots C are used for recording natural regeneration. Their centres are at a distance of 17.8 m from the centre of the main plot and located to the north, east, south and west. The radius of each subplot C is 2 m, covering an area of approximately 12.5 m² (the total area covered by the four subplots C is 50 m²). As detailed in Table 6.5, all trees that meet the diameter at breast height (DBH) or diameter at base (DAB) thresholds defined for each subplot type are recorded.

FIGURE 6.3

Plot design used to collect data for the Second National Native Forest Inventory

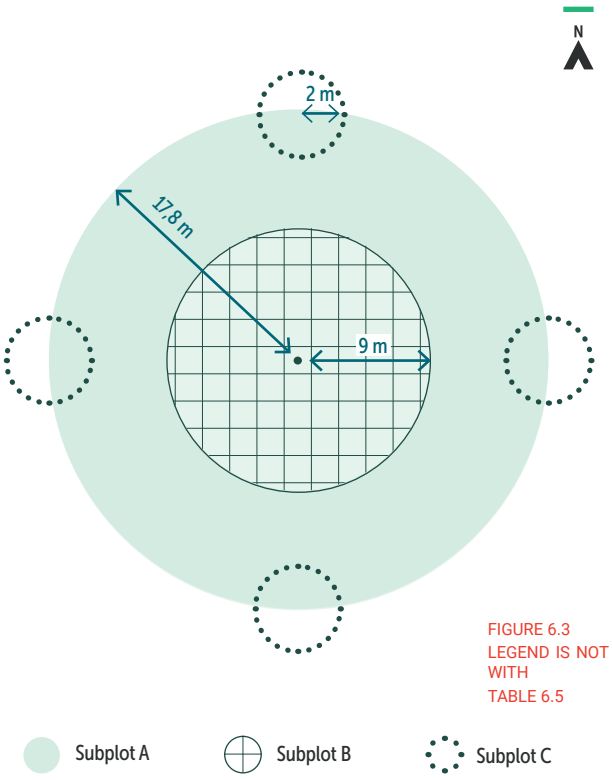


FIGURE 6.3
LEGEND IS NOT MATCHING WITH
TABLE 6.5

Source: **SAyDS**. 2019. Segundo Inventario Nacional de Bosques Nativos (INBN2): Manual de campo. Buenos Aires.

TABLE 6.5

Thresholds of diameter at breast height and diameter at base to select individuals in different forest regions

Units	Forest regions						
DBH/DAB (cm) Total height (m)	Chaqueño Park (PCH)	Yungas (YUN)	Paranaense forest (SPA)	Andean Patagonian Forest (BAP)	Espinal (ESP)	Paraná Deltas and Islands (DIP)	Monte (MON)
Subplot A	DBH ≥ 10	DBH ≥ 20	DBH ≥ 20	DBH ≥ 20	DBH ≥ 10	DBH ≥ 10	DBH ≥ 5 DAB ≥ 10
Subplot B	5 ≤ DBH < 10	10 ≤ DBH < 20	10 ≤ DBH < 20	10 ≤ DBH < 20	5 ≤ DBH < 10	5 ≤ DBH < 10	5 ≤ DAB < 10
Subplot C	DBH < 5 Total height ≥ 1,5	Clase 1 DBH < 5 Total height ≥ 1,5 Clase 2 5 ≤ DBH < 10 Total height ≥ 1,5	Clase 1 DBH < 5 Total height ≥ 1,5 Clase 2 5 ≤ DBH < 10 Total height ≥ 1,5	Clase 1 DBH < 5 Total height ≥ 1,5 Clase 2 5 ≤ DBH < 10 Total height ≥ 1,5	DBH < 5 Total height ≥ 1,5	DBH < 5 Total height ≥ 1,5	DAB < 5 Total height ≥ 0,5

Note: The diameter at base (DAB) is measured at 0.1 m (10 cm) above ground level and only in the sampling units corresponding to the MON forest region, due to the special characteristics of the predominant vegetation in the region. Measurements are made with a caliper (forest gauge, graduated in millimeter) or diameter tape. In the subplots C, two classes are differentiated for the YUN, SPA and BAP regions based on the size of the diameter at breast height (DBH) and always with a height greater than or equal to 1.5 m.

Source: **SAyDS**. 2019. Segundo Inventario Nacional de Bosques Nativos (INBN2): Manual de campo. Buenos Aires.

First, the variables recorded within the sampling unit include the identification number of the SU, number of pages of the worksheet, crew officer, number of crew members, survey date, work start time, work end time, grid coordinates, coordinates at the centre of the SU, coordinates of the reference point, reference data for access and observations.

In addition, the following data are considered for trees, both living and dead: the record number, azimuth and distance to the plot centre of the reference individuals, species, total height, crown diameter (only for Monte), condition, number of stems, DBH, DAB (only for Monte), stem length, stem health, stem shape and tree regeneration (quantity and species). Regarding the characteristics of the SU site, the type of landscape, altitude, slope, exposure, erosion, salinity, life forms, vegetation cover, fallen woody material and non-wood forest products (NWFP) are recorded. Finally, the variables referring to anthropic actions are recorded in each SU if there is evidence of fire, grazing/livestock, erosion and logging.

The installation of plots was carried out by teams of subcontracted professionals under different modalities (tender, contract or agreement), who were trained and continuously supervised by the DNB's technical team. In the case of the permanent BAP plots, these were partly installed by professionals under an agreement between the DNB and the Andean Patagonia Forest Research and Extension Centre (Centro de Investigación y Extensión Forestal Andino Patagónico – CIEFAP, according to its acronym in Spanish) and through a national public tender. Field data were stored in a digital platform and then processed and analysed to estimate the average parameters for the region.

6.5 LAND AREA AND VOLUME CALCULATION

Estimates of native forest area in 2017 and forest types in the Andean Patagonian Forest region were made using state-of-the-art geomatics tools and a semi-automated process of satellite image mosaics from the Landsat series. Details of the procedures and results can be found in Mohr-Bell *et al.* (2019). Volume calculations were performed separately for each of the stems. Species-specific volumetric equations were used (Table 6.6), provided that the DBH of the stem fell within the range specified for the equation. For those species where no volumetric equations were available in the literature and for trees with a size exceeding the specified DBH range for their species, the

volume was estimated with a general *equation* (FNNFI stem analysis). In cases where the stem length was not recorded or was longer than the total height of the individual, a volume value was randomly assigned within the distribution range of the estimated values for stems within the same DBH category.

6.6 RESULTS OF THE SECOND NATIONAL NATIVE FOREST INVENTORY

The SNNFI results are presented solely for the Andean Patagonian Forest, as this is the only forest region for which a second revision of results is available. A summary is shown in Table 6.7. The area of native forest in the BAP forest region was estimated at 3 240 996 hectares (ha), representing 16 forest types, with the following three being the most prominent: 49 percent corresponds to Lenga beech (*Nothofagus pumilio*) forests, 26 percent to Ñire (*Nothofagus antarctica*) forests, and 7 percent to Coihue (*Nothofagus dombeyi*) forests. Figure 6.4 shows the forest distribution map of the BAP forest region.

A total of 6 908 living trees were recorded with a DBH greater than or equal to 10 centimetres (cm). The average density of living trees was 479.93 individuals per hectare. Table 6.7 shows the estimated area of native forest and estimated tree density, basal area and volume with their respective mean, lower limit and upper limit of the 95 percent confidence interval for live individuals with DBH greater than or equal to 10 cm.

TABLE 6.6

Equations for the calculation of volume

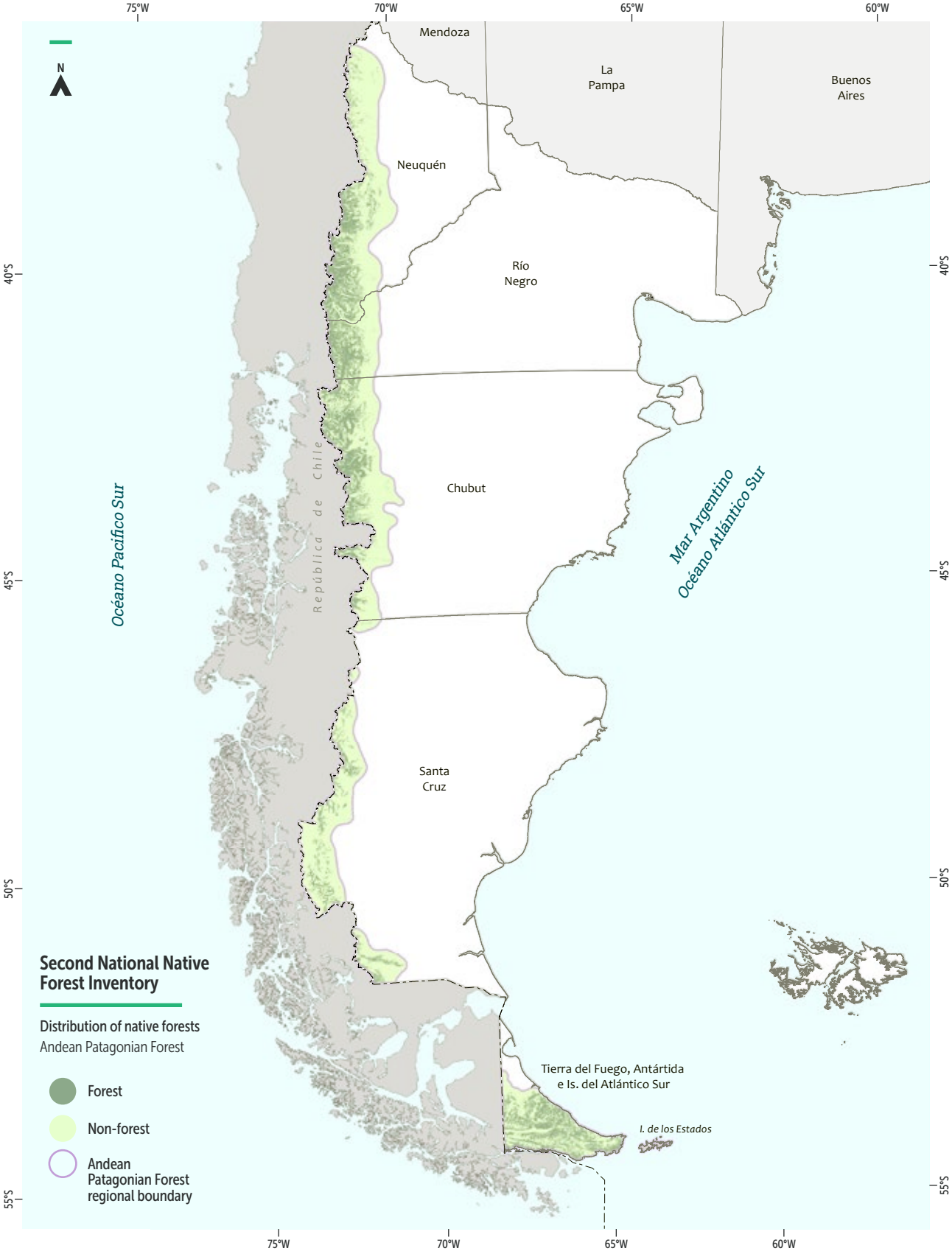
Volume (m^3)			
Species	Equation	Range of diameter	Reference
Araucaria araucana	$V = (0.00573 + 0.54939 \times DBH^2) / 1000$	Not applicable	Orfila (1970)
Austrocedrus chilensis	$V = 0.000253 \times DBH^{2.28315}$	10 cm – 50 cm	Chauchard *et al.* (1991)
Lomatia hirsuta	$V = -0.0467 + 0.0077 \times DBH$	5 cm – 40 cm	Reque *et al.* (2007)
Nothofagus alpina	$V = (0.000059 \times DBH^{1.9919} \times H^{0.8760}) \times 0.83$	5 cm – 118.5 cm	Chauchard, González Peñalba and Lara (2005)
Nothofagus antarctica	$V = (0.5933 / 1000) \times DBH^{2.1633} \times H^{0.6817}$	3.5 cm – 61 cm	Lencinas *et al.* (2002)
Nothofagus dombeyi	$V = (0.0000518 \times DBH^{2.0241} \times H^{0.8993}) \times (0.7559 + (5.3731 / DBH))$	5.1 cm – 104 cm	Chauchard, González Peñalba and Lara (2005)
Nothofagus obliqua	$V = (0.000059 \times DBH^{1.9919} \times H^{0.8760}) \times 0.83$	5 cm – 118.5 cm	Chauchard, González Peñalba and Lara (2005)
Nothofagus pumilio	$V = 0.00005522 \times DBH^{1.9677} \times H^{0.9583}$	1.1 cm – 108.8 cm	Martínez-Pastur (2005)
Pinus ponderosa	$V = (0.0298 + (0.0327 \times DBH^2 \times LS)) / 1000$	7.5 cm – 57.5 cm	Andenmatten, Rey and Letourneau (1995)
Schinus patagonicus	$V = (0.0106 + 0.0135 \times DBH)^2$	3.7 cm – 12.8 cm	Gyenge *et al.* (2009)
General equation	$V = 0.07307 + 0.00005407 \times DBH^2 \times LS$	10.4 cm – 107.7 cm	SAyDS (2005b)

Note: This table details the specific equations available for the species of the Andean Patagonian forest region. A general equation is used for those species for which it is not possible to apply a specific equation. The DBH for which each equation is applicable and the reference from which each equation was obtained are specified (MAyDS, 2020b). DBH: diameter at breast height; H: total height; LS: length of stem; V: volume of stem with bark.

Source: **Andenmatten, E., Rey, M. & Letourneau,** F.J. 1995. Pino ponderosa (*Pinus ponderosa*) (Dougl.) Laws. Tabla de volumen estándar de aplicación en la región Andina de Río Negro y Chubut. In: M.I. Zingoni, ed. *Actas de IV Jornadas Forestales Andino Patagónicas, vol. 1*, pp. 266–271. San Martín de los Andes, Argentina. **Chauchard, L.M., González Peñalba, M. & Lara, M.** 2005. Familia de funciones de volumen individual para *Nothofagus* nervosa, N. obliqua y N. dombeyi (unpublished).; **Chauchard, L.M., Rey, M. & González Peñalba, M.** 1991. Funciones de volumen para ciprés de la cordillera (*Austrocedrus chilensis* (D. Don.) Pic. Serm. et Biz.). In: *Actas de las VI Jornadas Técnicas: Inventarios, Modelos de Producción y Crecimientos Forestales*, pp. 40–48. Eldorado, Argentina.; **Gyenge, J., Fernández, M.E., Sarasola, M., Urquiza, M. & Schlichter, T.** 2009. Ecuaciones para la estimación de biomasa aérea y volumen de fuste de algunas especies leñosas nativas en el valle del río Foyel, NO de la Patagonia Argentina. *Bosque*, 30(2): 95–101.; **Lencinas, M.V., Martinez Pastur, G., Cellini, J., Vukasovik, R., Peri, P. & Fernandez, M.C.** 2002. Incorporación de la altura dominante y la clase de sitio a ecuaciones estándar de volumen para *Nothofagus antarctica* (Forster f.) Oersted. *Bosque*, 23(2): 5–17.; **Martínez Pastur, G.** 2005. Biometría y producción forestal para bosques naturales de *Nothofagus pumilio* en Tierra del Fuego. Buenos Aires, Argentina, Universidad Nacional del Sur. PhD dissertation.; **Orfila, E.N.** 1970. Tabla local de cubicación para *Araucaria araucana* en la zona del lago Moquehue, Neuquén, Argentina. *Revista Forestal Argentina*, 14(3).; **Reque, J.A., Sarasola, M., Gyenge, J. & Fernández, M.E.** 2007. Caracterización silvícola de ñirantales del norte de la Patagonia para la gestión forestal sostenible. Bosque, 28(1): 33-45. **SAyDS**. 2005b. *Primer Inventario Nacional de Bosques Nativos: Manual de análisis de fustes. Anexo I: Modelos de volumen.* Buenos Aires.

FIGURE 6.4

Distribution of native forests in the Andean Patagonian Forest Region



The boundaries shown and the names and designations used on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any countries, territories, cities, areas, authorities, or delimitation of their frontiers or boundaries. Dotted lines on maps represent approximate boundaries for which there may not yet be full agreement. A dispute exists between the Governments of Argentina and the United Kingdom of Great Britain and Northern Ireland concerning sovereignty over the Falkland Islands (Islas Malvinas).

Source: **MAyDS.** 2020b. Segundo Inventario Nacional de Bosques Nativos (INBN2): Informe Región Forestal Bosque Andin Patagónico – Segunda revisión. Buenos Aires.; **Mohr-Bell, D., Díaz, G., Príncipe, R., Gonzalez, C., Bono, J., Ciuffoli, L., Strada, M.,** *et al.* 2019. M*onitoreo de la superficie de bosque nativo de la República Argentina: Región Forestal Bosque Andino Patagónico.* Tomo I Informe. Esquel, Argentina, Secretariat of Environment and Sustainable Development.

TABLE 6.7

Second National Native Forest Inventory results: Andean Patagonian Forest region

Variable	Result	Description
Forest land area (ha)	3 240 996	Estimated land area of native forests for the Andean Patagonian Forest region distributed in the provinces of Neuquén, Río Negro, Chubut, Santa Cruz and Tierra del Fuego, Antarctica and South Atlantic Islands (Mohr-Bell *et al.*, 2019; SAyDS, 2019)
Density (individuals per ha)	479.93	Lower limit: 424.95 individuals/ha Upper limit: 534.91 individuals/ha
Basal area (m^2/ha)	39.52	Lower limit: 36.52 m^2/ha Upper limit: 42.53 m^2/ha
Volume (m^3/ha)	302.00	Lower limit: 269.10 m^3/ha Upper limit: 334.90 m^3/ha

Source: **MAyDS.** 2020b. *Segundo Inventario Nacional de Bosques Nativos (INBN2): Informe Región Forestal Bosque Andin Patagónico – Segunda revisión.* Buenos Aires.

6.7 IMPLEMENTATION AND QUALITY CONTROL

Plot installation activities in the BAP forest region were outsourced under the close supervision of the DNB technical team. In the case of the permanent plots presented in this report, dasometric data in 201 permanent plots were recorded through an agreement between the DNB and CIEFAP, and the 29 remaining installed plots were assessed through a national public tender. The crews in charge of installing the plots in the field were trained by the DNB to be qualified to install SUs following the instructions of the field manual (SAyDS, 2019) and were supervised by inventory plot coordinators. The crews consisted of at least three people: a crew officer, a technical assistant and a field assistant. The crews recorded data on the forest crop in the field worksheets (dasometric and site data and interventions carried out), which were then uploaded to the Open Foris Collect (OFC, an initiative developed by FAO) data storage platform. Once uploaded, these SPs became SUs that could then be monitored and analysed for data processing. The data uploaded to the OFC digital platform is verified to identify the variables where the most errors are repeated, in relation to the interpretation of the field manual during the measurement of the variables or during data uploading. This information is used to provide feedback to the contracting authorities and field staff in order to continuously improve the criteria used in measuring variables.

The area to be monitored and the potential SUs to be audited were established for the supervision and verification of the plot installation and recording of field data. All inputs were gathered and campaigns and activities were organized to notify the service provider (to verify authorisations to access the plots) and the local Application Authority (for potential collaboration). Technicians from the DNB carried out field data quality control activities using their own measuring instruments. Finally, in order to have a reliable database, prior to data analysis, the SNNFI information was cleaned and unified (typographical and qualitative variable coding errors were corrected and measurement units were standardized).

6.8 OTHER RELEVANT VARIABLES TO BE COLLECTED

As part of Argentina's commitments under the United Nations Framework Convention on Climate Change (UNFCCC), the information gathered from national inventories is of great relevance for reporting the level of greenhouse gas (GHG) emissions and removals from the country's native forest resources.

According to the Intergovernmental Panel on Climate Change (IPCC) guidelines, human-induced changes in carbon stock in biomass, dead organic matter and soil organic carbon should be reported in national GHG inventories (IPCC, 2006).

In cases where these carbon pools are of very small magnitude, and thus monitoring their changes is irrelevant, their measurement can be excluded. However, this must be demonstrated and reported through a specific study. Currently, the SNNFI collects information on volume and dead wood, as shown in Table 6.2.

In order to assess the need and relevance of monitoring carbon pools that were not measured in the SNNFI, with the support of the National UN-REDD Programme of the National Directorate of Climate Change of the MAyDS, a series of pilot studies have been carried out in the country's main forest regions to collect information about carbon content in dead wood, soil organic carbon and leaf litter. In addition, these studies are intended to test field measurement methodologies and propose those that are most appropriate in relation to the information obtained and the economic benefit of their application.

The collection of field data was carried out on a sample of the SNNFI permanent plots, randomly selected with regard to their accessibility, most representative forest types, and environmental, physiognomic and functional characteristics, in order to ensure the representation of forest carbon stock in each region.

6.9 FUTURE PROSPECTS

The Second National Native Forest Inventory of Argentina is the result of a significant effort and collaboration between people, institutions and projects. It required a consistent methodology and logistics for the collection and subsequent analysis of field data, resulting in robust information on the characteristics and state of the country's forest resources. In this sense, it is essential to provide continuity to the tasks carried out by the SNNFI and to ensure that the information generated is available to the various actors involved in forest resources, as a basis for guiding territorial planning and decision-making aimed at the sustainable management and conservation of native forests.

In particular, following the completion of the field activities in March 2020, data is available from 3 796 permanent plots distributed in the seven forest regions, out of a total of 4 158 plots identified as points that could be inventoried. In the short term, it is expected to advance with a national report that gathers the results of Argentina's seven forest regions. It is also intended to produce joint publications with other areas of the MAyDS on above-ground biomass and carbon content. In this regard, a pilot inventory has been carried out in six of the seven forest regions to improve the variables for estimating forest carbon, including other sources of carbon storage and sequestration (leaf litter and soil organic carbon), and to improve the measurement of dead wood. In addition, the results will be made available within the framework of the National Native Forest Monitoring System so that they can be consulted and used for different management, research and productive development initiatives.

In the medium and long term, the objective is to move forward with a strategy to ensure the permanence of the national inventory, which is carried out regularly and is based on permanent sample plots that are measured in different cycles, thus making it possible to compare and evaluate the evolution of native forests. To this end, reflecting on the experience acquired during previous inventories from a technical, operational and financial point of view will be necessary, as part of a process of continuous improvement. Furthermore, the implementation of Argentina's law on native forests and the commitments made at the international level in terms of climate change and biodiversity conservation have given rise to new demands for information on native forests that could be considered in future cycles of the national inventory. Measurements and estimates of soil, vegetation of the different non-tree strata, use and historic use of forests, fauna habitat and social aspects are some of the possibilities that will have to be assessed and will define the changes to be introduced in future inventories; such elements would enable both the comparison and acquisition of additional information under an integrated approach to native forest ecosystems.

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NEXT CHAPTER

BAHAMAS

Chapter 7

BAHAMAS

NATIONAL FOREST INVENTORY OF THE BAHAMAS

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7.1 HISTORICAL OVERVIEW OF NATIONAL FOREST INVENTORIES IN THE BAHAMAS

The Bahamas possesses considerable natural forest resources consisting of pine forests, coppice hardwoods and mangrove forests. The country has had a long history of forest exploitation dating back to the 1700s, when almost the entire hardwood resource was exploited as logs for export. The last extensive exploitation ended in the early 1970s when the pine forests were harvested for pulpwood.

The first forest assessment was carried out in 1956, prior to the pulpwood exploitation, on the islands of Grand Bahama and Abaco (Northern Bahamas). This assessment was initiated by a former logging company which inventoried the area of pine forest on Crown Lands (government-owned) within their designated concession areas (Henry, 1974). The overall objectives of the assessment on Grand Bahama were to estimate the area of pulpwood as solid volume in cubic metres and cords, and to estimate the area of different site qualities of pine forest. While on Abaco, the objective was to estimate the area of timber types (Henry, 1974). Unfortunately, the details of both surveys and figures for different sections of the islands are not available. Therefore, there is no way to adequately identify the methodology applied, the adequateness, completeness or accuracy of the survey data (Henry, 1974).

Following the assessments in Grand Bahama and Abaco, in 1961, interpretation of aerial photography was used to determine the areas of pine forest on North Andros Island (Henry, 1974).

In 1984, a project under the Technical Cooperation Programme of the Food and Agriculture Organization of the United Nations (FAO), titled "Forest Development Assistance," was implemented to carry out a forest land utilisation and inventory survey on 348 000 acres (141 000 hectares) of forest lands in Abaco, Andros and Grand Bahama islands (Allan, 1986).

The overall objectives of this inventory were the following:

- determine the area of ground covered by pine;
- classify pine forests by age and stand density;
- determine stand volume and stem size;
- assess the density and condition of regeneration;
- estimate growth rates of sampled stands;
- identify stands and areas of particular scientific interest;
- collect botanical samples of pine trees.

The major components of this inventory were aerial photograph interpretation and mapping, field inventory and data processing (Allan, 1986).

The sampling methods for the field inventory involved two stages: i) random and ii) systematic random sampling.

To execute this survey, known forest areas were divided into 48 blocks: 15 blocks on Abaco, 25 blocks on Andros, and 8 blocks on Grand Bahama. These blocks were subdivided into compartments approximately 500 acres in size. The total number of compartments summed to 186 on Abaco, 380 on Andros and 127 on Grand Bahama (Allan, 1986). Forest type maps for each island (Abaco, Andros, Grand Bahama and New Providence) were produced as part of this initiative.

In the first stage of sampling, two compartments in each block were chosen by random number, whereas the second stage consisted of a randomly sited systematic point sample of not more than 16 points laid out as a grid with 200 metres (m) between each point within each of the selected compartments (Allan, 1986).

Under the auspices of the project Forest Management and Innovation funded by the Global Environment Facility and which focuses on integrating biodiversity and ecosystem services into forest management and land use planning, a National Forest Inventory (NFI) is planned to be carried out on Crown Lands and National Parks in the Northern Bahamas. The primary objectives and monitoring considerations of this regional field survey are linked to forest productivity and carbon sequestration. Initially, the survey will be collected through the establishment of 96 random permanent sampling units (PSUs) in all cover types on National Forest Estate (NFE) land on the islands of Abaco, Andros, Grand Bahama and New Providence. These PSUs will be revisited at five-year intervals to collect new data, but also during quality control and quality assurance (QA and QC) procedures.

The NFI design (USDA, 2016) will allow monitoring future expansion and intensification to other lands and islands by applying a spatially balanced sampling method using Geographic Information Systems (GIS). Remote sensing data and technologies will be used to optimize the inventory by using post-stratification based on current maps or Collect Earth Online classification of a large sample of points on fine resolution imagery (Westfall *et al.*, 2019). Because the estimation of change is important, all plots will be permanent. As such, the value of any pre-stratification would tend to degrade over time, thus post-stratification of permanent sample plots distributed in a spatially balanced manner was chosen (GFOI, 2020). The NFI will be a component of the National Forest Monitoring System (NFMS), and data derived from the NFI will be used to facilitate policy decisions related to sustainable forest management throughout the Bahamas.

A summary of the history of the NFI in the Bahamas is presented in Table 7.1.

TABLE 7.1

Historical description of forest inventories

Inventory cycle	Execution period	Level	Sampling design	Number of sampling units
Pine forest area assessment (Grand Bahama) and timber types (Abaco)	1956	Subnational (Grand Bahama and Abaco)	None	5
Pine forest area assessment	1961	Subnational (North Andros)	None	54
Forest land utilisation and inventory survey (Forest Development Assistance)	1984	Subnational (Abaco, Andros and Grand Bahama)	Systematic/random sampling	48
National Forest Inventory	2021	National (initially subnational)	Spatially balanced	96

Source: **Allan, T.G.** 1986. *Management Plan for the Pine Forests of the Bahamas.* Nassau, FAO.; **Forestry Unit.** 2021. Field Instructions for Bahamas Forest Inventory. Nassau, the Bahamas; **Henry, P.W.** 1974. *The pine forests of the Bahamas. Land Resource Study 16.* Surbiton, UK, Overseas Development Administration, Land Resources Division.

7.2 TERMS AND DEFINITIONS

The terms and definitions applied in previous inventories do not include specific definitions for forest area, volume and biomass. The current definition of forest area adheres to the FAO variables and thresholds (Table 7.2). The definitions of other wooded land and other land are not defined for the NFI, because they are not included in the sampling priorities; these terms are used by the country only for Global Forest Resources Assessment (FRA) reporting.

Volume and biomass definitions for the NFI will depend on international and/or regional definitions and have not been determined.

Forest types used in the NFI include pine forests, coppice forests, mixed forests and mangrove forests. A summary of the forest type definitions is shown in Table 7.3.

TABLE 7.2

Summary of definitions used to implement the National Forest Inventory

Término	Definition	Variables and thresholds
Forest	Forest is defined as a land area of more than 1.2 acres (0.5 hectares) with trees achieving a height of at least 16.4 feet (5 metres) at maturity and a canopy cover of more than ten percent, and which is primarily not under agricultural or other specific non-forest land use.	Land area > 1.2 ac (0.5 ha) Tree height > 16.4 ft (5 m) Canopy cover > 10%
Other wooded land	N/A	N/A
Other land	N/A	N/A
Volume	Not yet defined	N/A
Biomass	Not yet defined	N/A

Note: N/A: not applicable.
Source: **Forestry Unit**. 2021. Field Instructions for Bahamas Forest Inventory. Nassau, the Bahamas.

TABLE 7.3

Summary of forest type definitions used to implement the National Forest Inventory

Term	Definition	Key features of the definition
Pine forest	The pine forest is dominated by the Caribbean pine, *Pinus caribaea* var. *bahamensis*. The forests support a diverse herb layer and an understorey vegetation consisting of palms and hardwood shrubs. It is the only canopy species found in an ecosystem of rocky, limestone soils. Within the Bahamian Archipelago, only four of the islands of the Bahamas support pineland vegetation: Andros, Abaco, Grand Bahama, and New Providence.	Dominant species: *Pinus caribaea* var. *bahamensis*
Coppice forest	The coppice forest is the most diverse forest in the Bahamas with many different trees. Coppice plants are considered the broad-leaved plants. Two types of coppice forest are found in the Pine Islands: whiteland coppice and blackland coppice.	Forest management: coppicing
Mangrove forest	Mangroves are a type of salt-tolerant tree, growing in shallow salt or brackish waters in creeks and on the coast of Bahamian islands. Four different types of mangroves can be found: red mangrove (*Rhizophora mangle*), black mangrove (*Avicennia germinans*), white mangrove (*Laguncularia racemose*) and buttonwood (*Conocarpus erectus*).	Habitat: plant assemblage or mangal
Mixed forest	Mixed pine and coppice forest dominated by either pine or coppice.	One-third of the canopy cover is pine and one-third is coppice. If one type reaches two-thirds of the canopy cover, pine or coppice forest is used instead.

Source: **Giri, C.** 2019. Forest Cover Classification System of Pine Islands. Forestry Department. Nassau, the Bahamas.

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7.3 SAMPLING DESIGN

The NFI is being designed and built up in stages. The current survey, which began in 2021, focuses on the NFE, which encompasses the northern islands of Abaco, Andros, Grand Bahama and New Providence, dominated by pine forests (Figure 7.1). These islands are the largest and contain much of the commercial forest in the Bahamas. The two subsets of NFE lands that are currently being sampled are the conservation forests and forest reserves. Conservation forests are forest areas where the extraction of forest and/or non-timber forest resources is prohibited. These areas are for the permanent protection of the ecological, scientific and cultural aspects of these forest areas. Forest reserves are forest areas that allow for the sustainable use and/or extraction of forest resources. The sampling units are distributed in a spatially balanced way across the two areas without regard to them being forest or non-forest. For the Pine Islands (Abaco, Andros, Grand Bahama and New Providence), 96 sampling units were selected, with 51 distributed in NFE conservation forests and 45 in NFE forest reserves; of these, 56 sampling units are located in forests and 40 in other lands (Table 7.4).

Post-stratification methods will be used to improve the precision based on the forest cover maps available at the time of each survey cycle or using Collect Earth Online to classify many points on fine resolution imagery. The PSUs will facilitate remeasurement and the estimation of the components of change.

In the future, it is anticipated that the NFI will be expanded to the rest of the Pine Islands and then to the entire country. This will be done by treating the two kinds of NFE lands as two subpopulations and the rest of the Pine Islands as a third subpopulation, because its sampling intensity will likely be less than for NFE lands. The rest of the country could be sampled at the same intensity as the remainder of the Pine Islands, in which case it would be included in the third subpopulation; if not, it would become a fourth subpopulation. For estimation purposes, post-stratification using a recent land cover map, developed by the Forestry Unit, would likely be applied to each subpopulation. In the case where there is no recent map of land cover/use, double sampling for post-stratification (Westfall *et al.*, 2019)

could be applied by stratifying hundreds or even thousands of points on fine-resolution imagery evenly distributed across the subpopulations. Sampling units would be distributed across each subpopulation in a spatially balanced manner without regard to current land cover.

7.4 SAMPLING UNIT DESIGN

The overall objectives of the Bahamas NFMS are to track changes over time with respect to forest productivity and carbon sequestration. Some indicators are related to tree abundance, tree growth/mortality, biomass/production, carbon balance, and land cover and land use.

The NFI sampling unit design is described in the Forest Inventory and Analysis National Core Field Guide (USFS, 2016), based on a cluster of two circular plots, where various data are collected (Figure 6.2).

The two circular plots have a 15-metre-radius circle, where all trees with diameter at breast height (DBH) of 30.0 centimetres (cm) or more are measured; each plot centre is 30 m apart at an azimuth of 360°.

After the plot centre has been established, the condition(s) of the plot (encompassing both subplots) is identified. A condition is defined as an area of relatively uniform ground cover, such as a homogenous vegetation cover (ecotype). A contrasting condition class is one that is different from the previously assigned condition class based on the defining attributes. Other relevant variables collected are tree canopy and ground cover, down woody material (DWM), tree and sapling details, mangrove tree species, tree data, seedling details, shrubs and invasive plant species, crown class, tree damage and decay class.

For mangrove forest conditions where tidal fluctuations inundate the plot area, only the canopy cover is recorded. Due to the growth form of the dwarf mangrove species, specific tree data collection procedures are established. For mangrove tree species, only crown canopy size, height, diameter and crown depth are recorded. Distance, bearing and diameter are taken on the tallest stem of the red mangrove clump. Diameter at breast height is collected 30 cm up from the last established prop root (BFD, 2016).

Each plot has different types of subplots. Subplot 1 consists of an 8-metre-radius circle, where all trees with DBH of 10.0 cm or more are measured. On each subplot 1, the three most dominant shrub species are recorded, and the area of canopy cover is estimated (to the nearest class). In addition, the total shrub cover of all species over the entire subplot and invasive species are collected in subplot 1.

Subplot 2 is a smaller circle with a 2.5-metre radius, offset from each plot centre by 5 metres at 90 degrees, where all saplings and seedlings are registered (USFS, 2016). Tree sapling details to be recorded include status, condition, class, tree species, bearing, horizontal distance, diameter, total tree length, live crown length, tree crown class, tree damage and severity.

Two categories of DWM are considered: coarse woody debris (CWD) with a diameter greater than or equal to 10.0 cm; and fine woody debris (FWD) with a diameter less than 10.0 cm. All DWM in the NFI is sampled using the line intersect sampling method. In this method, transects are established, and individual pieces of CWD and FWD are recorded if the central axis of the piece is intersected by the line of the transect. Leaf litter and duff measurements are also collected at the 8-metre point on each transect.

7.5 CALCULATION OF FOREST AREA, VOLUME AND BIOMASS

The equations used for volume and biomass/carbon calculations have not yet been determined. Thus, regional and/or international equations will be applied.

7.6 RESULTS OF THE MOST RECENT NATIONAL FOREST INVENTORY

The results of the most recent National Forest Inventory have not yet been obtained, as the Forestry Unit is currently in the measurement phase.

TABLE 7.4

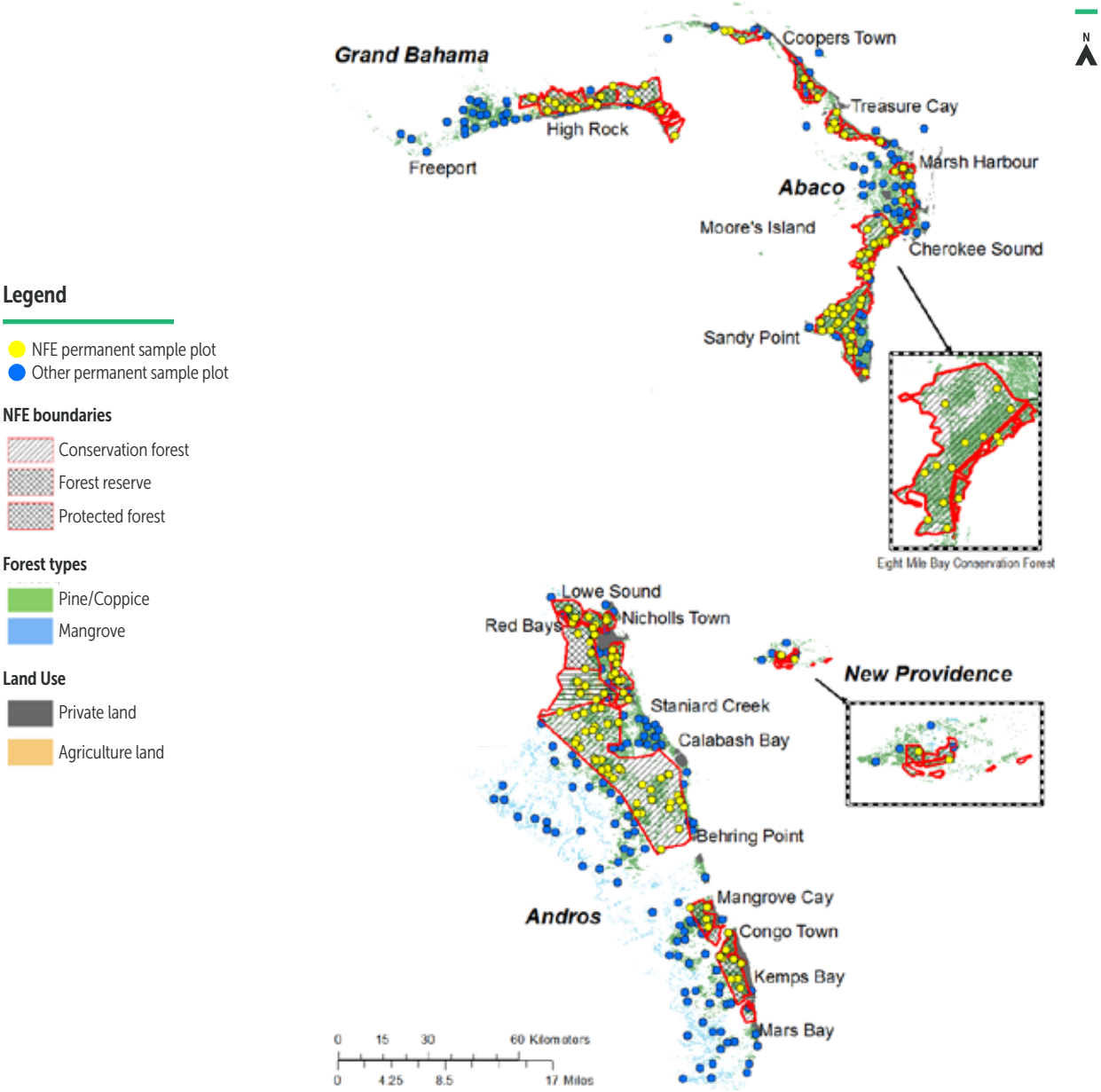
Characteristics of the sampling design

Region	Total area (1 000 ha)	Number of sampling units			Total number of sampling units
		Forest	Other wooded land	Other land	
National Forest Estate conservation areas	353	28	0	23	51
National Forest Estate forest reserves	300	28	0	17	45
Total	**653**	**56**	**0**	**40**	**96**

Source: Prepared by the authors.

FIGURE 7.1

The National Forest Inventory sampling design



The boundaries shown and the names and designations used on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any countries, territories, cities, areas, authorities, or delimitation of their frontiers or boundaries. Dotted lines on maps represent approximate boundaries for which there may not yet be full agreement.

Note: NFE: National Forest Estate.

Source: **Forestry Unit.** 2018. Bahamas Forest Inventory Sample Plot Location. Nassau, the Bahamas.

7.7 IMPLEMENTATION AND QUALITY CONTROL

No data exists on the spatial extent of forests and/or non-forest areas in the Bahamas, thus the establishment of a Land Cover Classification System and mapping project was critical to identifying these areas. Satellite images from Landsat-8 Operational Land Imager (OLI) with 30 m resolution were used to create a Land Cover Classification dataset for the NFI and, to a larger extent, for the Northern Bahamas (Abaco, Andros, Grand Bahama and New Providence).

To initiate the implementation of the NFI, a field manual (Forestry Unit, 2021) was developed to support the process of biophysical data collection by field crews; in addition, in order to ensure quality data collection, QA/QC principles were developed for the quality control teams. The field manual includes procedures to locate and establish field plots, measure and record information related to trees and other vegetation, coarse woody material, litter/duff, and provides the codes assigned to each data collection variable. The field manual also indicates the tolerance levels and compliance standards for the maximum accepted error of measurements.

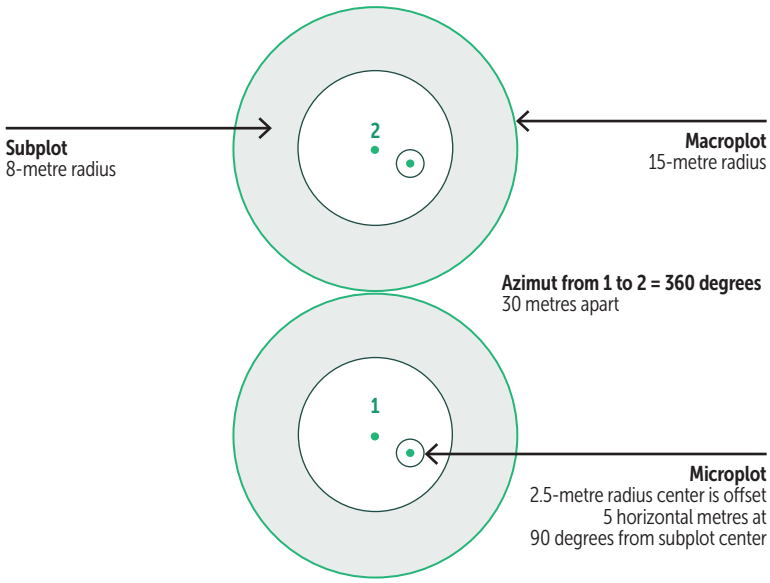
Furthermore, the field manual includes calibration and maintenance instructions for equipment that will be used during the data collection. Quality assurance involved the development of definitions, procedures and tolerance limits for errors. Another aspect of the QA for the NFI was the training and/or certification of officers to ensure that data is collected by officers in a consistent manner, using the same methods and tools.

Each PSU will be visited by a field crew of four certified officers. There are a total of eleven certified officers, including three women and eight men. The crew will operate in teams of two persons, each completing one subplot. Two QA/QC officers will accompany teams at all times to ensure that the data collected meet the minimum requirements of the quality standards defined. Data are considered to be of "acceptable quality" for the NFI if they meet the defined measurement quality objectives, specifically, the tolerance and compliance standards set for each variable.

Quality control will be implemented through database validation rules in Collect Mobile, the data collection tool created by Open Foris (www.openforis.org/). The validation methods that will be used are the following:

FIGURE 7.2

Sampling unit configuration of the National Forest Inventory



Source: **USDA (United States Department of Agriculture Forest Service)**. 2016. *Forest Inventory and Analysis National Core Field Guide (with Interior West Regional Additions). Vol. 1: Field data collection procedures for Phase 2 plots, Version 7.0.* Fort Collins, USA.

- allowed character checks;
- consistency checks;
- data type checks;
- logic checks;
- presence checks;
- range checks;
- uniqueness checks;
- field checks (hot, cold, blind).

Portable data recorders will be used to record valid answers, thus minimising the need for the data cleaning process.

7.8 FUTURE PROSPECTS

There have been many challenges related to the implementation of the NFI; most notably, the impacts associated with Hurricane Dorian in 2019, when the islands of Abaco and Grand Bahama were severely devastated. The current COVID-19 pandemic has also delayed the advancement of NFI activities due to travel restrictions and physical distancing measures in place to reduce and/or mitigate the spread of the virus.

Nevertheless, the Forestry Unit has completed the review and editing of the NFI field manual and also finalised the Land Cover Classification datasets. The Forestry Unit has also been engaged with teams to review the field manual and to carry out mock plot exercises to ensure the retention of data collection procedures.

The next steps to advancing the NFI implementation includes completing the sampling design, the data entry protocols, the validation rules for Collect Mobile, and creating plot packets for data collection teams. Medium-term goals include initiating and completing the NFI within two conservation forest areas on the islands of Grand Bahama and Abaco. Long-term plans will focus on the other components of the NFI, including analysis, reporting, data maintenance and sharing. Although the specific analytical and reporting tools to be used have not been determined, the Forestry Unit is considering Calc, the data analysis tool incorporated in Open Foris.

The implementation of the NFI is significant to the overall NFMS of the Bahamas. The NFI will facilitate the systematic collection, analysis and monitoring of periodic forest-related data through the establishment of PSUs. The PSUs will capture and provide pertinent details relating to natural and anthropogenic impacts on commercially viable timber resources and the overall forest ecosystem within the National Forest Estate.

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NEXT CHAPTER

BELIZE

Chapter

BELIZE

NATIONAL FOREST INVENTORY OF BELIZE

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8.1 HISTORICAL OVERVIEW OF NATIONAL FOREST INVENTORIES IN BELIZE

Belize's experience with forest inventories began centuries ago, during the colonial period. One of the first tasks of the early colonialist government in Belize was to quantify and characterize the country's natural resources. As with all land management endeavours, any decision regarding natural resource use must be informed by good-quality information on resource distribution and abundance. The forest estate of the country was divided into different blocks corresponding to production working circles, and initially logging commenced in the eighteenth century with cursory visual stock assessments. In the latter part of the nineteenth century, colonial foresters began the first commercial stock assessment of timber trees in different areas of the country (Bird, 1998). However, the objectives of such inventories did not advance much beyond simply estimating the stock of mahogany (*Swietenia macrophylla*) until the mid-twentieth century, when colonial foresters began to survey vegetation patterns, document the botany of the forest trees, and also repeat measurements of forest plots to determine growth and mortality. In the mid- to late twentieth century, colonial foresters began expanding forest inventories to cover full-scale assessments of the forest types within subnational-level management units; cumulatively, these covered close to 50 percent of the national forest estate, with a view to fully categorise the multiple strata into different forest types (see, for instance, Johnson and Chaffey, 1973).

The country's forest estate has traditionally been divided and managed according to distinct geographic blocks, corresponding to the boundaries of public forest reserves or privately owned forests. Within public forests, in some cases the separation into geographic blocks occurs along ecological lines. Management responsibilities and objectives often vary across the various forest blocks. As a consequence of this, or at least as a contributing factor, there has not been a coordinated attempt to implement the type of national forest inventory promoted in the region by the Food and Agriculture Organization of the United Nations (FAO). However, several forest blocks have been inventoried over the years for different purposes, with some blocks having multiple inventories at different scales (Table 8.1). Some inventories were designed to support forest management planning at the level of 1 to 2 percent sample intensity of an entire block, while others have been more diagnostic in nature at the sub-block level. There is also a permanent forest dynamics inventory ongoing since 1998, which currently includes 60 sampling units (SU) spread out over many forest blocks; this inventory is treated in more detail in the following paragraph. The important feature of this multi-inventory approach is that the methods have been standard across blocks and over time, and the data have been digitally archived.

Toward the end of the twentieth century, as an independent nation, Belize began initial work on the first component of a national level inventory of its forest resources, specifically to measure rates of different processes occurring in the forest, commencing in the 1990s with the installation of thirty permanent SUs, each measuring one hectare (ha) in size (Bird, 1998). Until this time, very little research had been conducted on the dynamic processes of tree growth, mortality and recruitment in the natural broadleaved and pine forests of Belize. The purpose of this new long-term inventory programme was to address the deficiency in information needed for forest management. The results of these permanent forest plot surveys provide the most comprehensive long-term data set to date on tree diversity, forest structure, forest growth, mortality and yield for the forests of Belize. Since 2010, the permanent forest inventory has expanded from the original 30 sample SUs established in the 1990s, concentrated mainly in the moist upland forests, to the current 60 SUs spanning the entire length and breadth of the country (Figure 8.1). The expanded network now encompasses forests in the three life zones found in Belize: dry, moist and wet.

The second component of the National Forest Inventory commenced in 2018, with the specific aim to measure the area and distribution of different forest types across Belize. This component involved a remote sensing assessment of forest cover and cover change from 2001 to 2015 by applying virtual permanent SUs established in the Collect Earth platform (Figure 8.2). This virtual forest cover inventory, coupled with the 60 permanent forest dynamics SUs, jointly comprise the National Forest Inventory of Belize and will also serve as the National Forest Monitoring System (NFMS) of Belize, to be formalized under the auspices of the Reducing Emissions from Deforestation and Forest Degradation (REDD+) mechanism. Belize's National

TABLE 8.1

Historical description of forest inventories in Belize

Inventory cycle	Execution period	Level	Sampling design	Number of sampling units
Land Resources Study	1969–1974	Subnational		
		– Mountain Pineridge Forest Reserve	Upland pine: stratified random point sampling	4 760 points
		– Southern Coastal Plains	Lowland pine: random rectangular plots (0.5 ha)	300 plots
		– Chiquibul Forest Reserve	Lowland broadleaf: random belt transects (10 ha or 16 ha)	50 transects
Forest Planning and Management Project (FPMP)	1992–1997	National	Random permanent sample plots (1 ha)	30 SUs
Natural Resources Institute	1994	Subnational	Upland pine: stratified random	> 100 SUs
Sustainable Forest Management Plans	2004–2013	National	Lowland pine and lowland broadleaf: stratified random belt transects (0.5 ha)	> 500 SUs
Forest Monitoring Network of Belize (FORMNET-B)	2009–present	National	Random permanent sample SU (1 ha), as in FPMP (old SUs re-measured and 30 new SUs installed)	60 SUs (current)
Collect Earth	2001–2015	National	Systematic virtual SU on one-kilometre grid	21 991 SUs

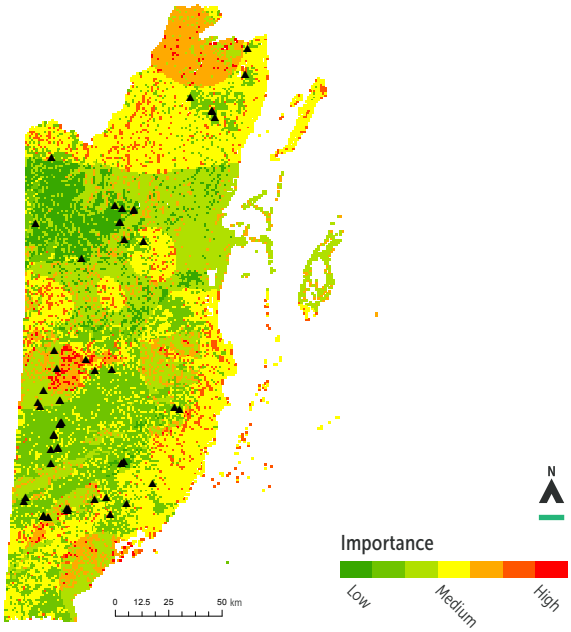
Source: Prepared by the authors.

Forest Inventory therefore utilises a two-phase forest inventory system, with tree-level inventory data producing estimates of stocks and stock change that are then extrapolated to the national level using remotely-sensed landscape level data on forest distribution and cover change.

As the twenty-first century began, additional static inventories took place at the subnational level to inform sustainable forest management plans for various forest blocks. The purpose of these inventories was to produce standardized data across management blocks that could inform landscape-level management, while at the same time being of sufficient sample size to inform site-level management. For the first time, commercial companies were responsible for carrying out the inventories, while under the supervision of the Forest Department. All inventories within broadleaved forests utilised similar sample designs and plot designs, which typically consisted of randomly stratified belt transects of 500 metres (m) by 20 m at 1 to 2 percent sample intensity. Small variations in subplot design were used when new or varied sample objectives were contemplated for different three-dimensional vegetation strata. Although comparable methods and sample designs were utilised across the various commercial inventories in the different forest types spanning most of the country, scientific rigour – in terms of the degree of botanical expertise involved in an inventory and whether assessments of measurement error were carried out – varied considerably from one inventory to the next. Nevertheless, the tree-level data from these inventories are representative of a large expanse of the country, and thus have proven useful in assessments of forest stock at the national level, especially when coupled with remotely sensed forest inventory data. Such forest inventory data produced by third parties are also incorporated into the NFMS and are partitioned to serve either as validation datasets or to aid extrapolation.

FIGURE 8.1

Sampling design of the National Forest Inventory forest dynamics component



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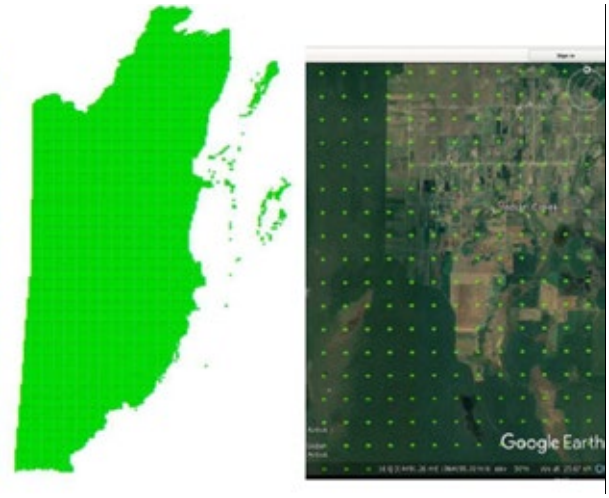
Note: Sixty permanent forest dynamics SUs (black triangles) are pseudo-randomly distributed across the country according to an importance index based on the representation of different forest types and environmental conditions such as rainfall.

Source: **Cho, P., Blackburn, G.A., Bird, N.M., Brewer, S.W. & Barlow, J.** 2013. The FORMNET-B database: monitoring the biomass and dynamics of disturbed and degraded tropical forests. *Journal of Vegetation Science*, 24(6), 1204–1207.

FIGURE 8.2

Sampling design of the National Forest Inventory remote sensing component



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Note: The virtual forest inventory design consists of 21 991 fixed location SUs, each 0.5 hectares in size, systematically distributed across the country to measure forest cover change.

Source: **Forest Department.** 2020. *Belize Forest Reference Level, 2001–2015.* Belmopan, Government of Belize.

8.2 TERMS AND DEFINITIONS

The terms and definitions relevant to the implementation of Belize's latest National Forest Inventory are based on national circumstances, but are for the most part aligned with the global definitions promoted by FAO. The definitions for the different forest types were extracted from Belize's "Forest Reference Level, 2001–2015" (Forest Department, 2020) and "Belize Collect Earth/Open Foris Land Use and Land Use Change Assessment Protocol" (Forest Department, 2019), and are provided in Table 8.2. Belize recognises various forest types, with the majority comprising mature broadleaved forest and pine forest. "Other land" or non-forest considers all land that is not classified as other categories in accordance with the Global Forest Resources Assessment (FRA) 2020 (FAO, 2020). Subcategories were also defined for some cover types, such as forest, due to the significant role of forest management in Belize; these include "regenerating forest" and "secondary forest."

8.3 SAMPLING DESIGN

The sampling design chosen for the National Forest Inventory (used here synonymously with NFMS) of Belize utilises multiple platforms and datasets. The Belize NFMS is a set of methods, activities and institutional arrangements that aim to produce high-quality, reliable data on human activities and ecosystem processes in forests, including estimates of forest carbon stocks and emissions; it is a key tool to assess whether the implementation of Belize's forest management and protection activities, policies and strategies are resulting in measurable benefits. The Belize NFMS uses a combination of remote sensing and ground-based inventory approaches. It provides internationally acceptable estimates that are transparent, consistent and accurate, with low levels of uncertainty, and that are rooted in national circumstances. To ensure effective use of limited resources, Belize's NFMS provides data and information for REDD+ measurement, reporting and verification, national greenhouse gas inventories, reporting progress towards nationally determined contributions (NDCs) and national forest management reporting.

TABLE 8.2

Summary of definitions used to implement the National Forest Inventory

Term	Definition	Variables and thresholds
Forest	Land with an area greater than or equal to 0.5 ha, with trees of 5 m or higher, and a canopy cover of 30% or more. This definition also includes forest plantation. In addition, it includes an ecosystem that due to biotic conditions (terrain, soil type, rainfall, etc.), the trees cannot grow higher than 5 m (e.g. some mangroves) or are currently below 5 m but are capable of attaining that height *in situ* (e.g. secondary forest).	Area ≥ 0.5 ha Height ≥ 5 m (with certain exceptions, e.g. mangroves, secondary forests) Canopy cover ≥ 30%
Other wooded land	Land not classified as "forest" spanning more than 0.5 ha; with trees or with a combined cover of shrubs, bushes and trees above 10%. It does not include land that is predominantly under agricultural or urban land use.	Area ≥ 0.5 ha Height not defined Cover of shrubs, bushes and trees ≥ 10%
Other land	All land that is not classified as "forest" or "other wooded land." An area that is 0.5 ha or more and that has 80 percent of soils that fall in subcategories such as bare soil, bare soil rocks and bare soil beach.	Area ≥ 0.5 h Cover of bare soil, bare soil rocks and bare soil beach ≥ 80%
Volume	Volume in cubic metres of the stem of trees 10 cm diameter at breast height (DBH) or greater, from ground level to the base of the crown, excluding defects.	DBH ≥ 10 cm
Biomass	Dry mass in kg of whole trees and logs occurring above ground.	DBH ≥ 10 cm

Source: Prepared by the authors.

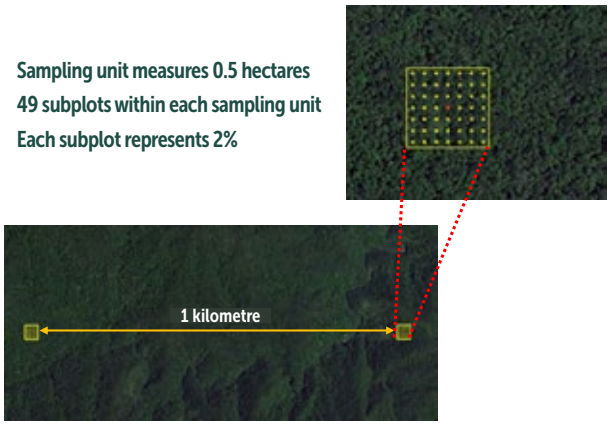
As discussed above in section 8.1, Belize's NFMS has two components: (i) a satellite land monitoring system and other data collection that provides information for anthropogenic activities affecting forest cover and distribution; and (ii) a ground-based national inventory utilising a network of 60 permanent SUs and other forest inventory data collected at the subnational level from time to time that provides information on ecosystem processes occurring within forests. The NFMS involves multiple institutions and independent experts functioning at different scales according to common methodologies, including the Forest Department, National Climate Change Office and the University of Belize Environmental Research Institute.

8.3.1 COMPONENT 1: SATELLITE LAND MONITORING SYSTEM

A one-kilometre (km) grid of virtual SUs is distributed systematically across the total land area of the country (22 110 km^2). A virtual 0.5 ha square plot, corresponding to the minimum area for national definitions for different land use categories, is situated at each grid point as per Figure 8.3 below. Each plot consists of 49 points, each representing 2 percent of the plot, which are used as subplots for the virtual sampling of forest cover.

FIGURE 8.3

Satellite land monitoring system sampling design



Note: A systematic one-kilometre grid is used to distribute 21 991 SUs, each measuring 0.5 hectares. The 21 991 SUs are permanent (with fixed coordinates) with the intent of continuous visual assessments to make accurate comparisons of the changes between land use/disturbance for each plot.

Source: **Forest Department.** 2020. *Belize Forest Reference Level, 2001–2015.* Belmopan, Government of Belize.

The design of the sample, that is, the grid of SUs where the land use, land use change and forestry (LULUCF) data are collected individually and used in Collect Earth, is based on a pre-estimation of the number of SUs required to reach a low sampling error, and practical matters such as the available time and workforce to carry out the assessment.

8.3.2 COMPONENT 2: FOREST MONITORING NETWORK OF BELIZE – GROUND-BASED PERMANENT FOREST INVENTORY NETWORK

Initially, the aim of the forest monitoring network in the 1990s was to select and monitor at least two SUs within different major forest classes in the Chiquibul Forest Reserve, Mountain Pineridge Forest Reserve, Columbia River Forest Reserve, Rio Bravo Conservation and Management Area, and Freshwater Creek Forest Reserve, five of the main production forest blocks at the time. The forest classes were determined by the national vegetation classification of Wright *et al.* (1959), and a stratification was developed to represent different levels of altitude, climatic conditions and disturbance, whilst ensuring accessibility. A total of 30 SUs were thus established in major forest classes according to levels of environmental variation (Figure 8.4).

In 2013, plans were drawn up to add 30 new SUs to the network to provide forest dynamics data from forest types that were currently unrepresented. In a geographic information system, spatial data on soils, rainfall, dry season length, altitude, aspect, forest type, land tenure, road access, ecosystems and plot representation were combined in a deterministic model to calculate an importance index for areas of forest that are currently unrepresented. The resolution on this model was 1 km^2, and it was used to determine the location of the 30 new SUs. The network of forest SUs has since been expanded to a total of 60, with new SUs in previously unrepresented forest blocks or forest types, utilising a similar stratification to ensure environmental representativeness (Figure 8.1).

The characteristics of the satellite land monitoring system and the ground-based permanent forest inventory are shown in Table 8.3.

TABLE 8.3

Characteristics of the sampling design

Country	Total area (1 000 hectares)	Number of sampling units			Total number of sampling units
		Forest	Other wooded land	Other land	
Belize (satellite)	2 211	13 059	2018	6 914	21 991
Belize (ground)	1 365	60	0	0	60
Total	**3 576**	**13 119**	**2 018**	**6 914**	**22 051**

Source: Prepared by the authors.

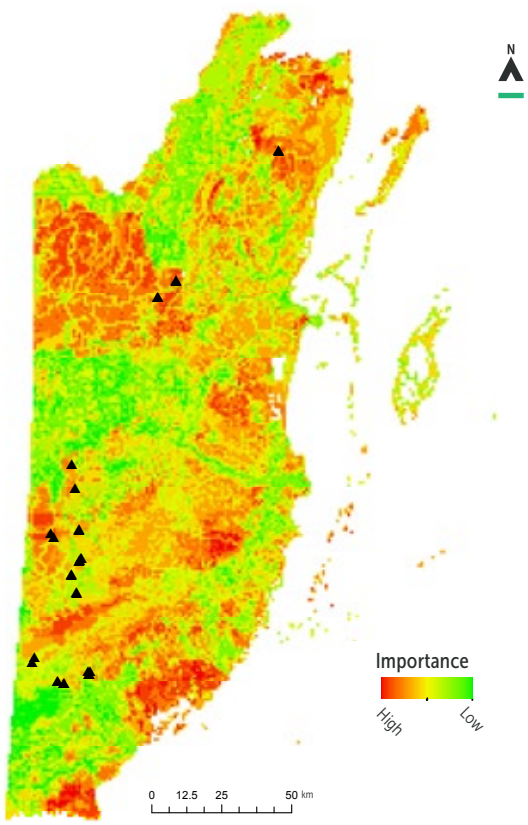
8.5 SAMPLING UNIT DESIGN

In the execution of the satellite land monitoring inventory, one type of virtual field plot is used. A virtual interpretation field plot measures 0.5 ha and has a total of 49 subsample points, with each point representing 2 percent coverage (Figure 8.5). These points are used to classify a plot as one of the six Intergovernmental Panel on Climate Change (IPCC) land use categories based on a majority principle. The classification of plots is based on national definitions and processes. The six main IPCC classes are forest, cropland, grassland, wetland, settlement and other land. Other variables collected during the given time periods include change from one category to the next, year of change, percentage of cover type, accessibility of sample plot from nearest road, disturbance and year of disturbance.

In the ground-based forest inventory, different types of SU designs are utilised, depending on the forest type and the objective. For permanent censuses in mature forests, to determine forest dynamics rates of broadleaved and pine forests, a square plot measuring 1 ha (100 m × 100 m) is utilised (Figure 8.6). Each plot is marked with long-lasting monuments and subdivided into 25 quadrats measuring 20 m by 20 m each. Stems with a diameter at breast height (DBH) greater than or equal to 10 centimetres (cm) are recorded within all quadrats except for quadrat 13, where stems with a DBH greater than or equal to 1 cm are recorded. Additional data recorded for each stem include easting and northing, climber presence, commercial height, defects, total height, crown position and crown form (Bird, 1998).

FIGURE 8.4

Original sampling design of the national permanent sampling units network consisting of 30 plots in the 1990s



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Note: The importance index shown was used to determine the location of 30 new sampling units (SUs). New SUs have been distributed within areas corresponding to importance of 80 percent or greater, resulting in the current plot distribution shown in Figure 8.1.

Source: **Cho, P., Blackburn, G.A., Bird, N.M., Brewer, S.W. & Barlow, J.** 2013. The FORMNET-B database: monitoring the biomass and dynamics of disturbed and degraded tropical forests. *Journal of Vegetation Science*, 24(6), 1204–1207.

For permanent monitoring of secondary forests, plots measuring 1/5 ha (20 m × 100 m) subdivided into five quadrats measuring 20 m by 20 m are used (Figure 8.7). Four such plots have been installed across the country. Data collected within the plot are as follows:

A. stems with a DBH greater than or equal to 10 cm are recorded within all quadrats. In addition to this, the easting and northing, climber presence, commercial height, total height, crown position and crown form are also recorded for each stem;

B. stems with a DBH greater than or equal to 1 cm and less than 10 cm are recorded;

C. woody and non-woody stems measuring less than 1 cm are recorded;

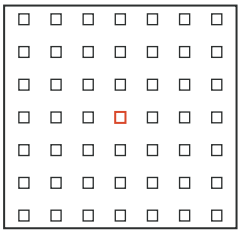
D. coarse woody debris measuring 10 cm or more are recorded;

E. samples of fine woody debris measuring from 1 cm up to 9.9 cm are collected;

F. samples of litter measuring less than 1 cm are collected.

FIGURE 8.5

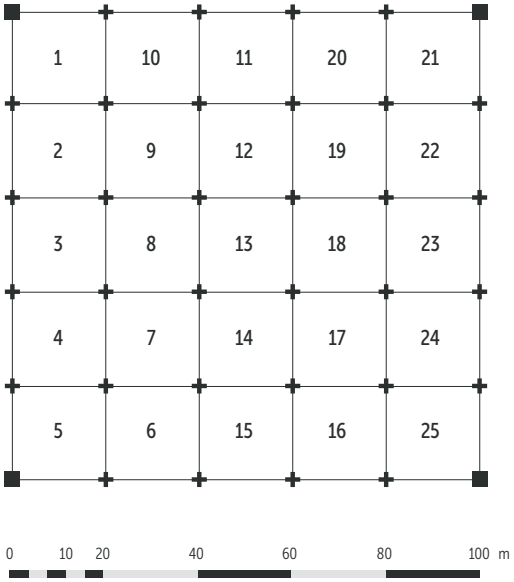
Layout of a 0.5-hectare (50 metres × 50 metres) virtual sampling unit for land use/land cover classification



Source: **Forest Department.** 2020. *Belize Forest Reference Level, 2001–2015.* Belmopan, Government of Belize.

FIGURE 8.6

Layout of a one-hectare (100 metres × 100 metres) permanent sampling unit



LEGEND

✚ 20 m internal corner post

■ exterior corner post

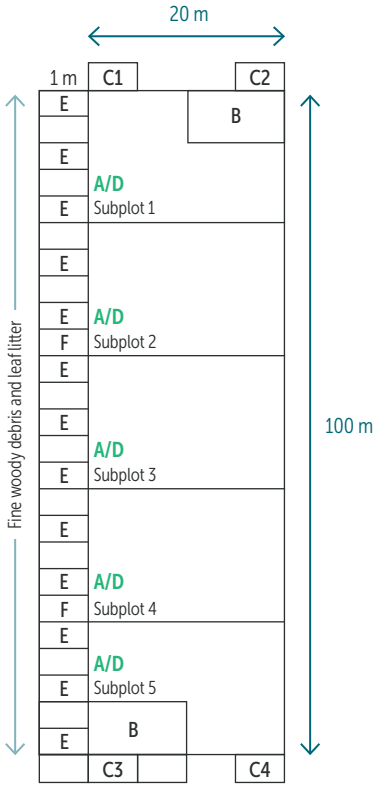
N

Note: Corner posts are true north, south, west, or east of each other and are represented by polyvinyl chloride pipes measuring 5.08 cm by 152 cm and driven to a depth of 30.5 cm.

Source: **Cho, P., Blackburn, G.A., Bird, N.M., Brewer, S.W. & Barlow, J.** 2013. The FORMNET-B database: monitoring the biomass and dynamics of disturbed and degraded tropical forests. *Journal of Vegetation Science*, 24(6), 1204–1207.

FIGURE 8.7

Layout of a 1/5 hectare (20 metres × 100 metres) permanent sample plot for secondary forests



Note: Corner posts are true north, south, west, or east of each other and are represented by polyvinyl chloride pipes measuring 5.08 cm by 152 cm and driven to a depth of 30.5 cm.

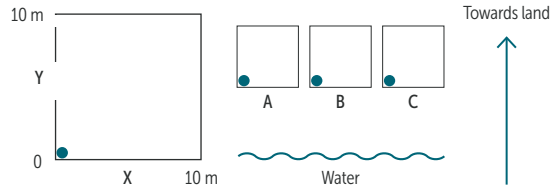
Source: **Forest Department.** 2020. *Belize Forest Reference Level, 2001–2015.* Belmopan, Government of Belize.

Permanent inventories of mangrove forests utilise SUs of triplicate plots measuring 10 m by 10 m each, with an approximate distance of 100 m from the water's edge (Figure 8.8). Ten such SUs have been installed in mangroves along the coast and on the offshore islands. Only trees with a diameter greater than or equal to 2.5 cm are monitored and both the total height and DBH are recorded for each.

For non-permanent forest inventories within broadleaved forests, plots measuring 0.5 ha (20 m × 250 m) aligned east to west are used. Each plot is subdivided into 10 quadrats measuring 10 m by 50 m each (Figure 8.9). A nested design is used wherein trees with a DBH greater than or equal to 25 cm are enumerated and measured across all quadrats, while trees measuring 5 cm to 9.9 cm and 10 cm to 24.99 cm are measured in two subplots each of 0.02 ha and 0.1 ha, respectively, in quadrats 1 and 7.

FIGURE 8.8

Layout of triplicate plots measuring 10 metres by 10 metres for mangrove forests

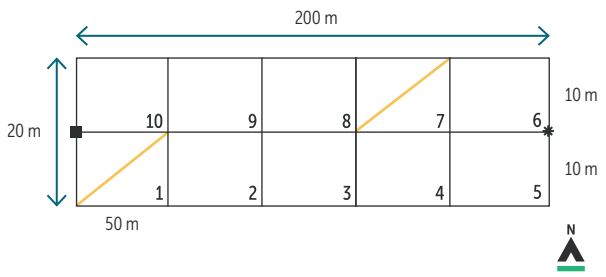


Note: The XY plotting technique is used within individual plots. The 0 point in each plot should be at the left-side corner closest to the ocean or lagoon, as shown above.

Source: **Almada-Villela, P.C., Sale, P.F., Gold-Bouchot, G., & Kjerfve, B.** 2003. *Manual of methods for the MBRS Synoptic Monitoring Program: Selected methods for monitoring physical and biological parameters for use in the Mesoamerican region.* Belize City, Belize, Mesoamerican Barrier Reef Systems Project.

FIGURE 8.9

Layout of a 0.5-hectare (20 metres × 250 metres) general broadleaved forest inventory plot



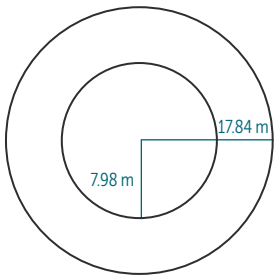
Note: Quadrats 1 and 7 constitute the subplots for trees measuring between 5 cm and 25 cm.

Source: **Forest Department.** 2020. *Belize Forest Reference Level, 2001–2015.* Belmopan, Government of Belize.

General inventories in pine forests utilise SUs of circular plots measuring 0.1 ha (17.84 m radius on flat ground). Within this, all live pine stems with a DBH greater than or equal to 25 cm are measured. Additional data collected include species, stem quality, crown form, log grade, bark beetle presence and cones. A subplot measuring 0.02 ha (7.98 m radius on flat ground) is then established and all live trees with a DBH between 15 cm and 25 cm are recorded (Figure 8.10).

FIGURE 8.10

Layout of general pine plot measuring 0.1 hectares (17.84-metre radius on flat ground) with a subplot measuring 0.02 hectares (7.98-metre radius on flat ground)



Source: **Pine Lumber Co. Ltd.** 2016. *Methodology for General Forest Inventory.* San Ignacio, Belize, Pine Lumber Co. Ltd.

8.5 CALCULATION OF LAND AREA, VOLUME AND BIOMASS

In satellite land monitoring, land area is calculated by the use of an expansion factor (*F*), represented by the following equation:

$$F_c = A_c / N_c$$

Where:

F_c = expansion factor of a plot in the country

A_c = land area of the country

N_c = number of SUs within the country

The expansion factor calculated in this way is equal to 100.53. Since the SUs are all distributed following the same systematic grid of 1 km by 1 km, the weight of the SU is always equal to 1 (all SUs represent the same area). The calculation of area of a given forest type is thus equal to the number of virtual SUs falling inside the forest type multiplied by a factor of 100.53.

Calculation of volume and biomass in ground-based inventories is dependent on the use of allometric models and volume expansion factors that are specific to species groups. Different local volume and biomass models exist for different groups of broadleaf species, for pines and for mangroves; these are listed in Table 8.4 below. Volume is tabulated per plot and then averaged for all SUs within a given forest type, and subsequently multiplied by the area of that forest type, in order to estimate national totals for forest volumes. The same tabulation procedure is used for biomass.

Equipment used to measure parameters for input into the volume and biomass equations include laser rangefinders for measuring height, diameter tapes for measuring diameter and calipers to measure the diameter of uneven stems. For biomass and volume, calculations are performed in a checksum-verified Excel spreadsheet and later transferred to a database for processing. Error and uncertainty are calculated within the database processing step using models developed from field measurements of user error of diameter and height and error estimates from the use of allometric models.

The volume and biomass models developed locally produce estimates with a total uncertainty of around 35 percent, with 27 percent contributed by measurement error and 8 percent contributed by the allometric equation (Cho, 2013).

8.6 RESULTS OF THE MOST RECENT NATIONAL FOREST INVENTORY

In 2018 and 2019, the satellite land monitoring component produced estimates of forest area and area change. These estimates were coupled with biomass stock data compiled from the ground-based permanent inventory SU to produce extrapolated estimates of biomass stocking for the entire country in mature forests.

An average stocking of 267 tonnes per ha of above-ground biomass (AGB) was used in the extrapolation.

The results are summarised in Table 8.5 below.

TABLE 8.4

Equations used for volume and biomass/carbon calculations

Variables	Equation	Reference
Total volume (m^3) **Broadleaved trees ≥ 10 cm**	$V = e^{(-9.480 + 0.975 \ln [DBH^2 H_S])}$	Cho (2013)
Total volume (m^3) **Pine trees ≥ 10 cm**	$V = e^{([2.4(lnDBH)] - 8.69)}$	Johnson and Chaffey (1973)
Biomass (g) **Mangrove trees ≥ 10 cm**	$AGB = 125.9571\ (DBH^2 H_T)\ 0.8557$	Cintron and Novelli (1984)
Biomass (t) **Pine trees ≥ 10 cm**	$AGB = (e^{([2.4(lnDBH)] - 8.69)})\ 0.0625$	Johnson and Chaffey (1973)
Biomass (t) **Broadleaved trees ≥ 10 cm**	$AGB = \frac{\rho\ (e^{(-9.480 + 0.975 ln\ [DBH^2 H_S])})}{1 - (0.723CFI - 0.091)}$	Cho (2013)

Notes: AGB: above-ground biomass; CFI: Dawkins Crown Form (Dawkins, 1958) expressed as a decimal percentage of 5; DBH: diameter at breast height, i.e. diameter in centimetres at 1.3 metres; g: grams; Hs: height in metres of stem from ground level to the base of the crown; HT: total height in metres; m^3: cubic metres; t: tonnes; ρ: wood density in grams per cubic centimetre obtained from the Global Wood Density Database (Zanne *et al.*, 2009).

Source: **Cho, P.** 2013. An investigation of tropical forest response to hurricane disturbance with evidence from long-term plots and earth observation in Central America. Lancaster, UK, Lancaster University. PhD dissertation.; **Cintron, G. & Novelli, Y.S.** 1984. Methods for studying mangrove structure. In: S.C. Snedaker & J.G. Snedaker, eds. *The mangrove ecosystem: research methods*, pp. 91–113. Paris, France, United Nations Educational, Scientific and Cultural Organization.; **Johnson, M.S. & Chaffey, D.R.** 1973. *A Forest Inventory of Part of the Mountain Pine Ridge, Belize.* Land Resource Study No. 13. Surbiton, UK, Land Resources Division, Overseas Development Administration.

TABLE 8.5

Results of the most recent cycle of the National Forest Inventory (2018)

Variable	Result	Description
Land area (1 000 hectares)	1 300,4	Total area of forest in 2018
Volume	n/a	n/a
Biomass (above-ground biomass in megatons)	347,2 (±27,7)	Total forest biomass in 2018
Carbon (above-ground carbon in megatons)	163,2 (±13,1)	Total forest carbon in 2018

Source: Prepared by the authors.

8.7 IMPLEMENTATION AND QUALITY CONTROL

Quality control and quality assurance activities conducted during the satellite land monitoring assessment were to have a second operator reassessing 5 percent of all the sample SUs of Belize. These sample SUs were randomly selected and ensured that the same operators were not reassessing themselves. It was noted that the coincidence level between the first assessment and the second assessment for forests was above 95 percent. Nevertheless, two additional reassessments of the uncertain SUs were conducted. All SUs were filtered using Saiku, a business intelligence tool, which enabled the identification of other uncertainties in the SU. Furthermore, all land use and land change data were imported into ArcMap to conduct further validation with queries for areas within protected areas. Finally, for quality assurance, a Sentinel-2 map using a wall-to-wall methodology was developed by an independent organization (Water Center for the Humid Tropics of Latin America and the Caribbean) and the overall results in forest areas was a difference of 1.26 percent.

Quality control in the ground-based permanent forest inventory consists of remeasurements of a subset of trees immediately after a census is performed. If the error in tree measurements is greater than 5 percent, the plot must be remeasured. In addition, data entry quality controls are applied to the transcription process to maintain an error below 5 percent.

In regard to the mangrove SUs, staff, interns and/or volunteers are trained in the methodology before plot surveys are conducted. The leader, usually a marine biologist, ensures that the team is accurately collecting data. Moreover, the same team conducts data collection at all the established sites. The marine biologist is responsible for data checks and any necessary cleaning of the data before they are analysed.

8.8 OTHER RELEVANT VARIABLES COLLECTED

In the Collect Earth data collection process, apart from the land use change assessment, disturbance was also noted within forest SUs. There are high and low levels of disturbance: high disturbance is when 35 percent or more of the plot is disturbed, and low disturbance is any disturbance that affects less than 35 percent of the plot. The types of disturbances considered are (i) natural disturbance or hurricane disturbance, which refers to natural disaster; and (ii) pest disturbance, which refers to insects that affect the tree species within its natural ecosystem, for example, southern bark beetle affecting the pine forest.

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8.9 FUTURE PROSPECTS

The evolution of Belize's National Forest Inventory continues under the auspices of the NFMS for REDD+. Collect Earth and other similar remote sensing methods represent half of the future advancements, but on-the-ground measurements are also expected to improve in accuracy as technology like laser measurement devices are enhanced. The harmonization of databases between satellite and ground-based inventories will also occur, utilising the latest in business intelligence tools. The future expansion of permanent SUs to other forest and vegetation types including non-forest cover will occur. Measurement variables will be expanded to include a coarse assessment of soil and climatic variables.

One challenge to future forest inventories is the loss of knowledge that occurs through "brain drain" or high turnover among trained technicians in the public and private sectors. Universities with long-term tenure arrangements are ideal places to embed this kind of knowledge, in order to avoid losing it through turnover.

Furthermore, the incorporation of gender considerations into the planning of capacity development for forest monitoring will be an important step to minimise loss of knowledge. In the 2018 Collect Earth campaign, women comprised 40 percent of the team of technicians. In the field, women account for between 20 and 40 percent of the team composition. With the strong participation of all genders in the forest monitoring programme of Belize, the chances of continued success in the future are high.

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NEXT CHAPTER

BRAZIL

Chapter 9

BRAZIL

NATIONAL FOREST INVENTORY OF BRAZIL

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9.1 HISTORICAL OVERVIEW OF NATIONAL FOREST INVENTORIES IN BRAZIL

Brazil is a large country with a territory covering 851 million hectares, of which about 57 percent is covered by forests, making it the second largest forest area in the world (FAO, 2020a). The country has 26 states and a Federal District, with a population of approximately 212 million inhabitants.

The first forest inventories in Brazil were carried out in the mid-1950s in the Amazon region, with the support of the Food and Agriculture Organization of the United Nations (FAO), covering about 19 million hectares in 13 areas of the region (Silva, 1996; SUDAM, 1974), with a view to establishing wood processing industries as part of a development strategy for the region. Between 1965 and 1979, three forest inventories were carried out in the south of the country focusing on Brazilian pine (*Araucaria angustifolia*), and additional inventories were undertaken in three states in the country's north-eastern region (Machado, 1984).

In the 1980s, in the context of the global oil crisis, the first edition of the National Forest Inventory (NFI) was prepared to explore the potential of forest biomass as an alternative to that situation. Field measurements were performed in natural and planted forests, with over 250 million hectares inventoried, with the exception of the Amazon, as this region had been covered by field measurements to map the region's natural resources as part of the RadamBrasil Project (IBGE, 2018). The first Brazilian NFI was coordinated by the federal government through the Brazilian Institute of Forestry Development and had regional support from universities and research centres through their forestry departments. This initiative was followed by forest inventories of large areas that focused on regional development. At the national level, the focus was more on the creation and strengthening of institutions (Bauch *et al.*, 2009), such as the Brazilian Institute of Environment and Renewable Natural Resources, created in 1989, and the National Forest Programme (NFP), created in 2000, among others. It was only in the context of the NFP that the NFI was revisited.

Given the need to have better forest information in the country, the NFI was reinstated in 2005, initiating a new process to define a methodology that could be applied to the various Brazilian biomes. In addition, it was deemed essential that this new NFI should have a wider coverage of forest attributes, broadening the scope beyond wood and seeking greater synergy with international processes such as FAO's Global Forest Resources Assessment (FRA) report (FAO, 2005).

A consultative process was coordinated by the Ministry of the Environment through the NFP and with the collaboration of several national institutions and

FAO. As a result, in 2006, a proposal for a single methodology for the NFI was presented, which included biophysical and socio-environmental information components. The proposed objective of the NFI was to produce information on forest resources, natural and planted forests every five years, in order to support the formulation of public policies for the use and conservation of forest resources.

In 2006, with the creation of the Brazilian Forest Service (SFB), which took over the coordination of the NFI, the testing phase of the methodology in Brazilian biomes and the search for funding for project implementation began.

The collection of field data was formally launched in 2011 (Table 9.1), through a project funded in collaboration with FAO with resources from the Global Environment Facility (GEF). Field data collection started in the Federal District (580 000 hectares), the smallest unit of the federation, located in the Cerrado (savannah) biome and where the SFB is headquartered (Brasilia). The work was carried out with the support of the University of Brasilia and served as the basis for refining the methodology, improving the field manual and structuring the training and quality control programmes. As the NFI progressed across the southern and north-eastern states, additional funding was made available for the Amazon biome (Amazon Fund) and for the Cerrado biome (Forest Investment Programme), and several state governments participated in the financing. The Brazilian NFI has not yet completed the measurement of all the sampling units planned for its first cycle. Several factors have contributed to the instability of its implementation process, the main one being the restricted financial execution pattern of the government's budgetary resources. By December 2019, NFI data collection had been completed in 18 of the 27 federal units, corresponding to about 50 percent of the country's land area, with 12 189 sampling units (SU) or clusters already measured, equivalent to 69 percent of the total number of SUs planned for the first cycle (Table 9.1). This difference is due to the fact that not all grid points in the Amazon were visited, due to difficult access, resource constraints and the exclusion of Indigenous lands in the first NFI cycle.

The NFI is provided for in the forestry code – Law 12651/2012 for the protection of native vegetation – and is coordinated by the SFB, which migrated from the Ministry of the Environment to the Ministry of Agriculture, Livestock and Supply (MAPA) in 2019. The NFI receives scientific support from the SFB and other Brazilian research institutions and universities through an informal technical and scientific advisory commission, the NFI Technical Committee.

The NFI has been implemented state-by-state, for operational and political reasons, but also at biome level, given each biome's peculiarities in terms of forest characteristics; this is also for funding reasons, as mentioned above. Figure 9.1 presents the distribution of NFI SUs in the six Brazilian biomes, including the state boundaries. From a biophysical point of view, biomes present differences in the dominant types of vegetation, as well as in the extent of the pressure on forests; for this reason, they are often used as a reference for the implementation of environmental public policies.

The Amazon biome with its lush tropical rainforest is located in northern Brazil, occupying 49 percent of the national territory; in the central part of the country is the Cerrado biome, the Brazilian savannah, which occupies about 24 percent of the country (Table 9.2); and the Caatinga biome (9.9 percent) is found in the northeast, with a predominance of steppe savanna, dry forests and a semi-arid region.

The Pantanal biome (1.8 percent), located in the western part of the country, is an alluvial plain with high biological diversity, especially of wild animals. The Atlantic Forest biome (13 percent) runs from north to south along the Brazilian coast, a region with a high population density and a history of significant pressure on forests.

TABLE 9.1

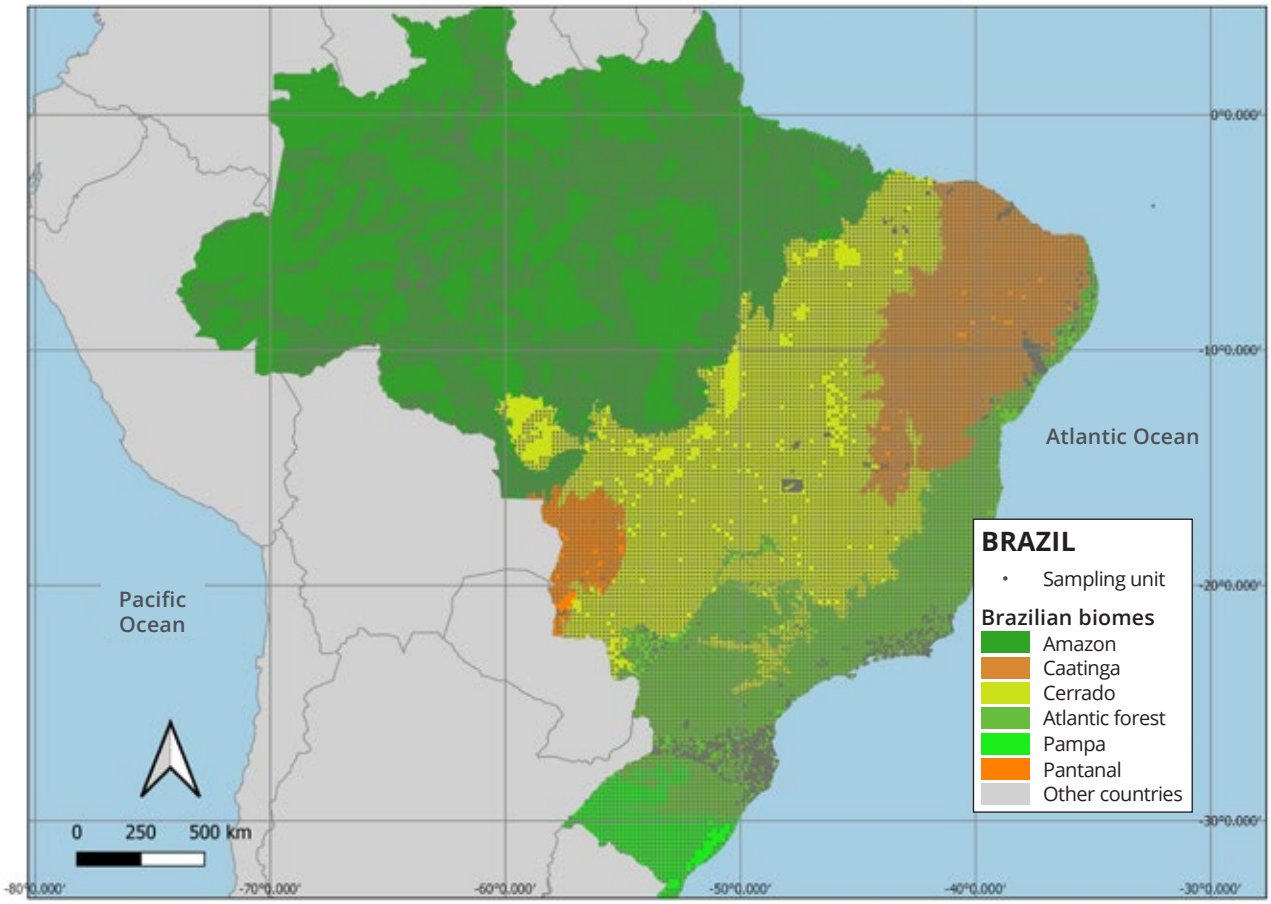
Description of the ongoing first cycle of the Brazilian National Forest Inventory

Inventory cycle	Implementation period	Scale	Sampling design	Number of expected sampling units
NFI-C1	From 2011	National	Systematic	17 587

Source: Prepared by the authors.

FIGURE 9.1

Map of the distribution of sampling units (clusters) in the six Brazilian biomes



The boundaries shown and the names and designations used on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any countries, territories, cities, areas, authorities, or delimitation of their frontiers or boundaries. Dotted lines on maps represent approximate boundaries for which there may not yet be full agreement.

Note: The sampling units are represented by the dark spots across the country, based on planning for the first cycle of the National Forest Inventory.
Source: Prepared by the authors.

In the extreme south of the country is the Pampas biome (2.1 percent), also known as the southern grasslands, which also extends across Argentina and Uruguay.

The purpose of this chapter is to describe the Brazilian National Forest Inventory, with an emphasis on the methodological aspects and the main results in the variables that have been prioritised for the harmonization of NFIs in the region, and to present some of the lessons learned and expectations from the implementation of the NFI in recent years.

TABLE 9.2

Sampling design characteristics: extension of each biome and number of sampling units planned for the first cycle of the National Forest Inventory

Region (biome)	Total land area (1 000 ha)	% of country	Number of sampling units
Amazon	419 694.30	49.30	5 884
Cerrado	203 644.80	23.90	4 823
Pantanal	15 025.50	1.80	373
Caatinga	84 445.30	9.90	2 371
Atlantic Forest	111 018.20	13.00	3 613
Pampa	17 649.60	2.10	523
Total	**851 477.70**	**100.00**	**17 587**

Source: Prepared by the authors with data from **SFB**. 2019d. Florestas do Brasil em Resumo: 2019. Brasília, Ministério da Agricultura, Pecuária e Abastecimento.

9.2 TERMS AND DEFINITIONS RELEVANT TO THE NATIONAL FOREST INVENTORY

The terms and definitions adopted for the main NFI variables, which involve estimates for large areas, were drawn up taking into account national definitions and classifications and, to the extent possible, those used by FAO in the most recent FRA process (FAO, 2010). Adaptations have been made to facilitate field identification and classification and to process vegetation map data, through the integration of typologies that converge with the definitions of forest and other wooded land.

Regarding the definition of forest, the forest typologies within the classification of vegetation of the Brazilian Institute of Geography and Statistics (IBGE, 2012) were equated with the FAO definition of forest definition , as shown in Table 9.3. With the help of experts specialised in such classifications, the characteristics of each vegetation type were assessed in relation to the main attributes of the FAO definition (Table 9.3). In addition, vegetation types that could be classified as other wooded land (OWL) and other land (OL) were listed. Thus, synergy was sought between the field data and the vegetation map used to extrapolate the forest category variables mapped by IBGE, based on the definitions that were adopted when developing the methodology (Table 9.4). The criteria for defining a forest are explained to the field teams during their training to ensure consistency in the field assessment.

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TABLE 9.3

Summary of definitions used to implement the National Forest Inventory

Term	Definition	Variables and thresholds
Forest	Land spanning more than 0.5 ha with trees higher than 5 m and a canopy cover of more than 10 percent, or trees able to reach these thresholds *in situ*. Areas for agricultural and urban use are not included. Vegetation categories of the Brazilian Institute of Geography and Statistics (IBGE) that meet the criteria of the FAO definition of forest.	Area ≥ 0.5 ha Potential height ≥ 5 m Canopy ≥ 10% Types of vegetation (IBGE)
Other wooded land	Land with vegetation types that do not meet the definition of forest due to tree characteristics or crown cover. IBGE vegetation categories that meet the FAO definition of other wooded land.	Canopy: 5%–10% Types of vegetation (IBGE)
Other land	Land with vegetation not classified by FAO as forest or other wooded land.	Land use categories
Volume	Volume of wood including bark, calculated from the stem to the commercial height, of all living trees with a diameter at breast height (DBH) greater than or equal to 10 cm, considering all tree species. To determine the stem volume, branches below commercial height are not considered, nor are specific stump records or estimates.	DBH ≥ 10 cm, tree species (palms are not included)
Biomass	Above-ground biomass: biomass of living trees, including stem, branches, leaves, flowers and reproductive structures. Below-ground biomass: biomass of roots, where possible, those with a diameter greater than 2 mm; based on conversion factors available in the literature. Dead wood: biomass of standing trees recorded as dead and of all woody material that has fallen on the ground with a diameter greater than 2.5 cm, irrespective of the state of decomposition.	DBH ≥ 10 cm, tree species and other life forms (e.g. palms) and boundaries as described in the adjacent definition

Source: Prepared by the authors with data from **FAO**. 2010. *Global Forest Resources Assessment 2010: Terms and Definitions*. Forest Resources Assessment Working Paper 144/E. Rome, FAO.; **IBGE (Brazilian Institute of Geography and Statistics)**. 2012. *Manual técnico da vegetação brasileira*. 2nd Ed. Rio de Janeiro, Brazil, IBGE.

TABLE 9.4

Summary of the classification of Brazilian vegetation and its correspondence with the categories of the Global Forest Resources Assessment

Formation subgroups (physiognomy)	Formations (environment/relief/trends)	Category Global Forest Resources Assessment 2020
Dense ombrophilous forest (FOD)	Alluvial FOD	Forest
	Lowland FOD	Forest
	Submontane FOD	Forest
	Montane FOD	Forest
	High montane FOD	Forest
Open ombrophilous forest (FOA)	Alluvial FOA	Forest
	Lowland FOA	Forest
	Submontane FOA	Forest
	Montane FOA	Forest
Mixed ombrophilous forest (FOM)	Alluvial FOM	Forest
	Submontane FOM	Forest
	Montane FOM	Forest
	High montane FOM	Forest

TABLE 9.4 (CONTINUED)

Formation subgroups (physiognomy)	Formations (environment/relief/trends)	Category Global Forest Resources Assessment 2020
Semi-deciduous seasonal forest (FES)	Alluvial FES	Forest
	Lowland FES	Forest
	Submontane FES	Forest
	Montane FES	Forest
Deciduous seasonal forest (FED)	Alluvial FED	Forest
	Lowland FED	Forest
	Submontane FED	Forest
	Montane FED	Forest
Campinarana	Forest Campinarana	Forest
	Woodland Campinarana	Forest
	Shrub Campinarana	Other wooded land
	Grassy-woody Campinarana	Other land
Savannah	Forest savannah	Forest
	Woodland	Other wooded land
	Park	Other wooded land
	Grassy-woody	Other land
Stepic savannah	Park	Other wooded land
	Grassy-woody	Other land
Steppe (fields in southern Brazil)	Park	Other wooded land
	Grass-woody (rural)	Other land
Pioneer formations	Tree (rocky headland)	Forest
	Shrub (dunes)	Other wooded land
	Herbaceous (beach)	Other land
	Tree (mangroves)	Forest
	Herbaceous (fluvial plains)	Other land
	Palm grove	Forest
	Shrub	Other wooded land
	Herbaceous	Other land
Floristic contact formations	Transition zones between vegetation types, which may be forest or non-forest	Forest
Secondary vegetation	Secondary tree vegetation in some areas exposed to human intervention	Forest
Planted forests	Eucalyptus, pine, acacia, carob, rubber, teak, among others	Forest

Source: Prepared by the authors with data from **FAO**. 2010. *Global Forest Resources Assessment 2010: Terms and Definitions.* Forest Resources Assessment Working Paper 144/E. Rome, FAO.; **IBGE (Brazilian Institute of Geography and Statistics)**. 2012. *Manual técnico da vegetação brasileira.* 2nd Ed. Rio de Janeiro, Brazil, IBGE.

9.3 SAMPLING DESIGN

The system is based on systematic sampling on a national grid of sampling points and fixed-area SUs (clusters). This grid was built for the whole country starting from a random point on the Equator within Brazilian territory. The standard distance between perpendicular sampling points is 20 kilometres (km); however, when resources are available, there is also the option of densifying the sample by reducing the distance between points in territories for which more detailed and precise information is desired. A denser sample may be justified for typologies of greater interest, very small states, municipalities, or when better information on a smaller administrative territory is required. In general, the SFB implements a standard grid (20 km by 20 km), but there are examples of implementing a 10 km by 10 km grid in the states of Santa Catarina (SFB, 2018), Rio de Janeiro (SFB, 2018) and Sergipe (SFB, 2017), among others; a 5 km by 5 km grid in the Federal District (SFB, 2016) and in the Municipality of Caçador (SFB, 2019a); and a 2.5 km by 2.5 km grid in the Mangueirinha Indigenous Territory (SFB, 2019b).

It is important to note that, except in these special cases, there is no prior stratification for the selection of sampling units to be measured. All grid points must be visited for data collection, regardless of whether they are located in forest areas. Grouping clusters for post-stratification is desirable and possible.

9.4 SAMPLING UNIT DESIGN

Sampling units are configured as clusters with four subunits that are aligned with the cardinal directions and located 50 m from the sampling point indicated by the national grid (Figure 9.2); the subunits are divided into subplots to approximate different inclusion boundaries (SFB, 2019c).

The standard subunits are rectangular, each one measuring 20 m by 50 m, equivalent to 1 000 square metres (m²). All specimens with a diameter at breast height (DBH) greater than or equal to 10 cm are measured, this being considered the main inclusion boundary for the NFI. Exceptionally, longer subunits (20 m by 100 m) are used in the Amazon biome, with only trees with a DBH of 40 cm or more being measured in the last 50 m. This strategy was adopted to better capture information from large trees, which tend to have a very low density and a greater contribution to variables such as volume and biomass in the overall calculation. The various levels of approach are presented in Table 9.5. Herbaceous plants (Level I) are only classified according to three categories of abundance or coverage and a photo of each plot (0.4 m × 0.6 m), thereby providing a database that can be consulted by specialists to guide research. There is no identification of herbaceous plants, but when fertile plants are found, they are collected for identification in herbaria.

Likewise, in the context of the SUs, two 10-metre transects that cross over the sampling point are used to assess dead and decaying wood, using

TABLE 9.5

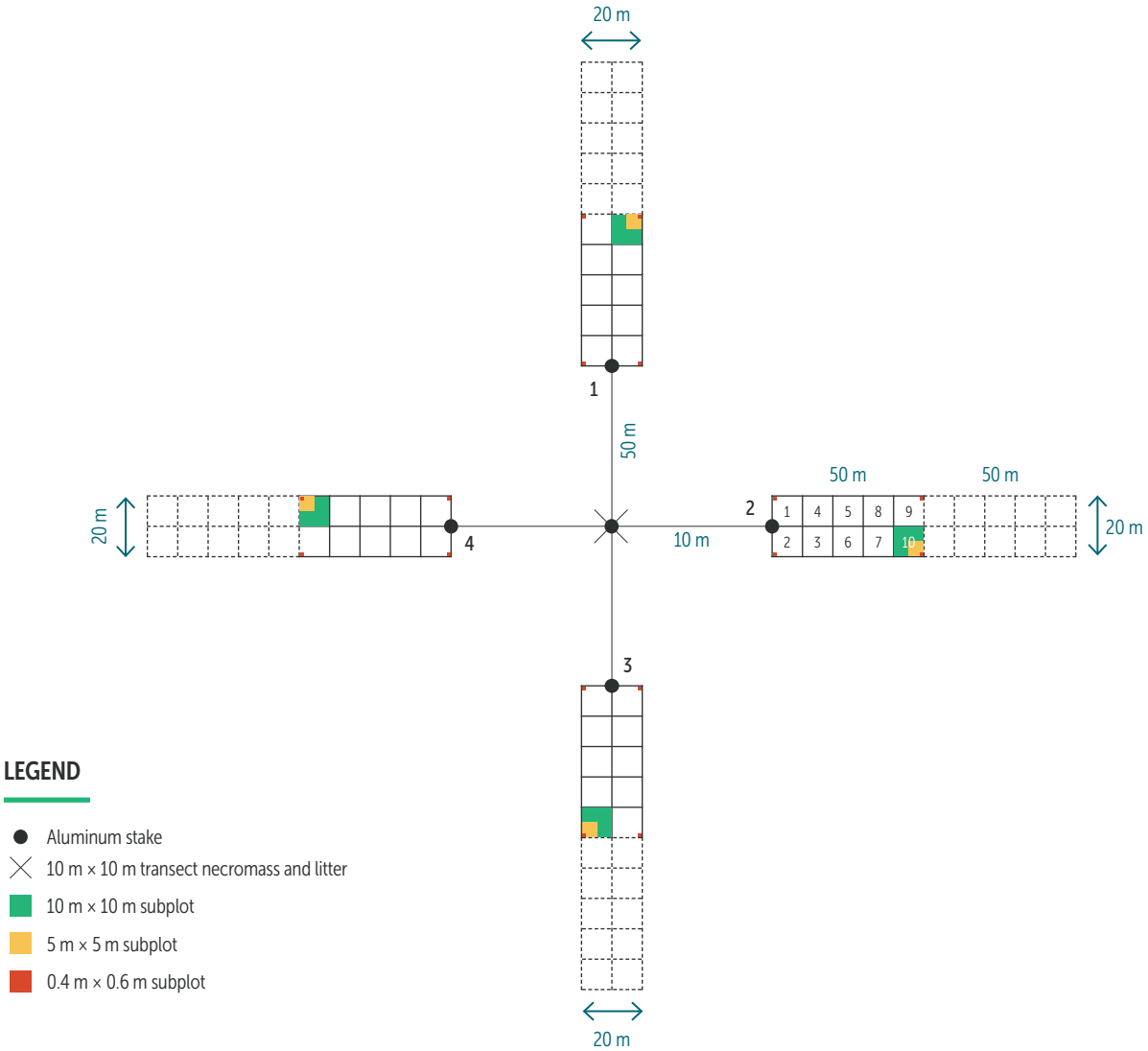
Dimensions of the sampling unit and subdivisions to address various levels of inclusion

Level of approach	Sampling unit dimension (m)	Inclusion limits	Biome
I	0.4 × 0.6	Herbaceous plants	All
II	5 × 5	Height ≥ 1.3 m Diameter at breast height (DBH) < 5 cm	All
III	10 × 10	5 cm ≤ DBH < 10 cm	All
IV	20 × 50	DBH ≥ 10 cm	All
V	20 × 100	DBH ≥ 40 cm (in the last 50 m)	Amazon

Source: Prepared by the authors.

FIGURE 9.2

Sampling unit (cluster) configuration, illustrating the additional length of the subunits in dotted lines



Note: The additional length of the subunits (20 m × 100 m) is illustrated with dotted lines; these are used only in the Amazon biome and only for recording trees with diameter at breast height greater than or equal to 40 cm.

Source: **SFB**. 2019c. *Manual de Campo: procedimentos para a coleta de dados biofísicos e socioambientais*. Brasilia, Ministry of Agriculture, Livestock and Supply.

transect line sampling (Shiver and Borders, 1995), and the depth of leaf litter is also measured at five points. Two soil samples are taken near the core of the SU at two depths (0 cm to 20 cm; and 30 cm to 50 cm): one bulk sample for chemical analysis and one undisturbed sample for the measurement of soil carbon stock.

An important aspect of the NFI sampling design is that, as a general rule, all grid points must be visited for data collection. This implies that the same cluster can cover more than one land use category, including forest and non-forest. Thus, each of the four subunits of the cluster is divided into subplots measuring 10 m by 10 m, and the predominant land use category (LUC) is recorded in each subplot using an NFI coding (IBGE, 2012; SFB, 2019c). In this way, the data processing is done on the basis of ratio estimates (Queiroz, 2012; Shiver and Borders, 1995) for the different LUC. The assessment to assign the forest use category in the field takes into account the same parameters as the FAO definition.

9.5 FOREST AREA, BIOMASS AND VOLUME ESTIMATES

9.5.1 LAND AREA

Land area calculations are necessary and important to guide the extrapolation of quantitative variables, such as volume and biomass, from field data collected across the territory. The Brazilian NFI has a geographical database for this purpose, which has been built and updated from various sources. The base map is the distribution map (1:250 000) of the original vegetation, including the distribution of native vegetation types, which was updated by IBGE with Landsat images from 2009. The update of land area estimates was based on all data available on forest loss in the country up to 2018, obtained from existing national satellite monitoring systems (MMA, 2016). These data allow for the calculation of land areas by vegetation type and can be updated whenever the monitoring systems update their own data. Experts in the classification of Brazilian vegetation at IBGE have compared FAO definitions of forest, other wooded land and other land with the vegetation classification (IBGE, 2012). In this way, it is possible to obtain the forest area by aggregating all national forest typologies that are equivalent to the FAO definition of forest, as well as the other categories.

Using this type of procedure, the SFB updates information about the country's forest area, which, in turn, is provided to the National Forest Information System (NFIS) and the NFI (SFB, 2019d). In this way, the area of each forest typology for any given territory can be determined, with the disaggregation for calculations by state and by biome being an essential aspect of the NFI.

9.5.2 VOLUME AND BIOMASS

Volume is calculated for tree species, and biomass also includes other life forms such as palms, bamboos and undergrowth (with DBH of 5 cm or more). Volume and biomass equations are obtained from existing literature and are selected based on information regarding the origin of the data used for the estimate – such as region or state, forest type, number of trees, range of data and their distribution in diametrical categories – and on precision measurements that characterize the quality of the estimate.

A database with detailed information on the equations found in the literature was developed to facilitate their selection. Table 9.6 presents information on some of the equations used in the volume and biomass calculations, solely for the states for which reports with NFI results have already been published.

9.6 PARTIAL RESULTS OF THE FIRST CYCLE: FOREST AREA, BIOMASS AND VOLUME

9.6.1 FOREST AREA

The forest area was calculated for the entire country by combining the types of vegetation classified as forests according to FAO criteria, and the annual forest losses recorded in all biomes by national monitoring systems (MMA, 2016), which are spatially explicit data. Therefore, the country's forest area can be updated virtually every year. Table 9.7 presents the values of forest area by biome for the reference year 2018 (SFB, 2019d).

9.6.2 VOLUME AND BIOMASS

Using the field data collected by the NFI, it was possible to estimate average volume (cubic metres per hectare) and biomass (tonnes per hectare) stocks for the main forest types in all biomes (Table 9.8). To obtain total estimates for each biome, in regions where field data were not yet available, average stocks of the desired forest type were used; these were obtained from areas within the same forest type and biome that had been measured and for which data already existed (FAO, 2020b). In this way, it was possible to produce volume and biomass estimates in areas that had not yet been covered by field data collection, including the number of SUs (n) used in each estimate (Table 9.9). While it was possible to make these estimates, it should be noted that the NFI is still in progress and that the overall results per biome will be corrected as soon as data collection is completed across the country.

TABLE 9.6

Equations used for volume and biomass calculations for states with completed data collection and published reports

Variables	Equation	Reference
Biomass (kg)	$B = 0.0612\ DBH\ H^{1.5811}$	Sampaio and Silva (2005)
	$ln\ (B) = 0.0298 \times DBH^2 \times H$	Rezende (2002)
	$ln\ (B) = -10.4843 + 1.6816 \times ln\ (DBH) + 1.4063 \times ln\ (Ht)$ $ln\ (B) = -10.5940591011 + 1.602721969 \times \ln (DBH) + 1.5878967963 \times ln\ (H)$ $ln\ (B) = -10.6409194002 + 2.1533324963 \ln (DBH) + 0.8248143766\ ln\ (H)$ $ln\ (B) = -10.9532786932 + 2.5464820134 \ln (DBH) + 0.4667754371\ ln\ (H)$	Scolforo *et al.* (2008)
	$ln(B) = -2.052 + 0.801\ ln\ (DBH^2\ H)$	Moreira-Burguer and Delitti (2010)
	$B = 0.317\ DBH^2 + 0.009\ (DBH^2\ H)$	Ratuchne (2010)
	$log\ (B) = -0.882390231 + 2.409594057 \times log\ (DBH)$	Vogel *et al.* (2006)
	$B = 25.87071 + 0.02909\ DBH^2 - 0.21382\ Ht^2 + 0.03189\ DBH^2\ Ht$	Silveira (2009)
Volume (m^3)	$ln\ (V) = -9.59340 + 2.04417\ ln\ (DBH) + 0.94531\ ln\ (H)$ $V = 0.000077\ DBH^{1.85794}\ Ht^{0.93919}$	Figueiredo Filho *et al.* (2014)
	$Vol\ (m^3) = 0.000109 \times DAB^2 + 0.0000451 \times DBH^2 \times H$	Rezende (2002)
	$ln\ (V) = -9.97595 + 2.05409 \times ln\ (DBH) + 0.87842 \times ln\ (Hc)$	Chichorro *et al.* (2003)
	$V = 0.4057 - 0.05955\ DBH + 0.00189\ DBH^2 + 0.00309\ DBH\ H - 0.000065\ DBH^2\ H - 0.02128\ H$	Thiersch *et al.* (2006)
	$V = 0.000074230 \times DBH^{1.707348} \times H^{1.16873}$ $ln\ (V) = -9.42719 + 1.96900\ ln\ (DBH) + 0.831852\ ln\ (H)$	CETEC (1995)
	$ln\ (V) = -9.7751 + 2.2403 \times ln\ (DBH) + 0.6308 \times ln\ (Ht)$ $ln\ (V) = -9.9752493252 + 2.1719145688\ ln\ (DBH) + 0.8083667085\ ln\ (H)$ $ln\ (V) = -9.7394993677 + 2.3219001043\ ln\ (DBH) + 0.5645027997\ ln\ (H)$ $ln\ (V) = -9.7677720672 + 2.4886704462\ ln\ (DBH) + 0.4406921533\ ln\ (H)$	Scolforo *et al.* (2008)
	$ln\ (V) = -8.875910 + 1.892219\ ln\ (DBH) + 0.739038\ ln\ (H)$	Santos *et al.* (2006)
	$ln\ (V/1000) = -17.96 + 0.96\ ln\ (CBH^2) + 0.76\ ln\ (H)$ $ln\ (V/1000) = -17.68 + 0.95\ ln\ CBH^2 + 0.67\ ln\ (H)$ $ln\ (V/1000) = -17.75 + 0.98\ ln\ CBH^2 + 0.57\ ln\ (H)$	Vibrans *et al.* (2015)
	$V = e\ [\ -9.5934 + 2.04417\ ln\ (DBH) + 0.94531\ ln\ (H)\ ]$	Figueiredo Filho *et al.* (2014)
	$ln\ (V) = -10.045586 + 2.349493\ ln\ (DBH) + 0.640598\ ln\ (H)$	Correia *et al.* (2017)
	$ln\ (V) = -9.3381 + 1.96993\ ln\ (DBH) + 0.837\ ln\ (Ht)$	Colpini *et al.* (2009)
	$ln\ (V) = -8.273 + 1.804\ ln\ (DBH) + 0.763\ ln\ (H)$	Cysneiros *et al.* (2017)

Notes: B: biomass (kg); CBH: circumference at breast height (cm); DBH: diameter at breast height (cm); DAB: diameter at the base of the stem (cm; for some trees in Cerrado); H: total height (m); Hc: commercial height (m); Ht: total height (m); V: volume.

Sources: **CETEC (Fundação Centro Tecnológico de Minas Gerais).** 1995. *Determinação de equações volumétricas aplicáveis ao manejo sustentado de florestas nativas no estado de Minas Gerais e outras regiões do país.* Belo Horizonte, Brazil.; **Chichorro, J.F., Resende, J.L.P. & Leite, H.G.** 2003. Equações de volume de taper para quantificar multiprodutos da madeira em floresta Atlântica. *Revista Arvore*, 27(6): 799–809.; **Colpini, C., Travagin, D.P., Soares, T.S. & Silva, V.S.M.** 2009. Determinação do volume, do fator de forma e da porcentagem de casca de árvores individuais em uma Floresta Ombrófila Aberta na regiao noroeste de Mato Grosso. *Acta Amazonica*, 39(1): 97–104.; **Correia, J., Fantini, A. & Piazza, G.** 2017. Equações volumétricas e fator de forma e de casca para florestas secundárias do litoral de Santa Catarina. *Floresta e Ambiente*, 24: e20150237.; **Cysneiros, V.C., Pelissari, A.L., Machado, S.A., Figueiredo Filho, A. & Souza, L.** 2017. Modelos genériocos e específicos para estimativa do volume comercial em uma floresta sob concessao na Amazônia. *Scientia Forestalis*, 45(114): 295–304.; **Figueiredo Filho, A., Machado, S.A., Miranda, R.O.V. & Retslaff, F.A.S.** 2014. *Compêndio de equações de volume e de afilamento de espécies florestais plantadas e nativas para as regiões geográficas do Brasil.* Curitiba, Brazil.; **Moreira-Burguer, D. & Delitti, W.B.C.** 2010. Modelos preditores da fitomassa aérea da Floresta Baixa de Restinga. *Revista Brasileira de Botânica*, 33(1): 143–153.; **Ratuchne, L.C.** 2010. *Equações alométricas para a estimativa de biomassa, carbono e nutrientes em uma floresta ombrófila mista.* Universidade Estadual do Centro-Oeste. Master's tesis.; **Rezende, A.V.** 2002. *Diversidade, estrutura, dinâmica e prognose do crescimento de um cerrado Sensu Stricto submetido a diferentes distúrbios por desmatamento.* Federal University of Paraná. PhD dissertation.; **Sampaio, E.V.S.B. & Silva, G.C.** 2005. Biomass equations for Brazilian semiarid caatinga plants. *Acta Botanica Brasilica*, 19(4): 935–943.; **Santos, K., Sanquetta, C.R., Eisfield, R.L., Watzlawick, L.F. & Zillioto, M.A.B.** 2006. Equações volumétricas por classe diamétrica para algumas espécies folhosas da floresta ombrófila mista do Paraná, Brasil. *Revista Ciências Exatas e Naturais*, 8(1): 99–112; Scolforo, J.R., Mello, J.M. & Oliveira, A.D. 2008. Inventário Florestal de Minas Gerais – Cerrado. Lavras, Brazil, Editora UFLA.; **Scolforo, J.R., Mello, J.M. & Oliveira, A.D.** 2008. *Inventário Florestal de Minas Gerais – Cerrado.* Lavras, Brazil, Editora UFLA.; **Silveira, P.** 2009. Ajuste de modelos matemáticos para estimar biomassa aérea em floresta ombrófila densa. *Floresta*, 39(4): 743752.; **Thiersch, C.R., Scolforo, J.R, Oliveira, A.D., Maestri, R. & Dehon, G.** 2006. Acurácia dos métodos para estimative do volume comercial de clones de Eucalyptus sp. *CERNE*, 12(2): 167–181.; **Vogel, H.L.M., Schumacher, M.V. & Trüby, P.** 2006. Quantificação da biomassa em uma floresta estacional decidual em Itaara, RS, Brasil. *Ciência Florestal*, 16(4): 419–425.

TABLE 9.7

Forest area calculated in the context of the National Forest Inventory in each Brazilian biome, 2018

Biome/specific type	Forest area (ha)	Percent of biome	Percent of total forests
Amazon	320 510 860	76.4	64.2
Caatinga	36 268 803	42.9	7.3
Cerrado	76 170 531	37.4	15.3
Atlantic forest	19 260 873	17.3	3.9
Pampa	2 651 967	15	0.5
Pantanal	5 542 334	31.4	1.1
Secondary vegetation	28 142 657	-	5.6
Planted forests	10 503 326	-	2.1
TOTAL	**499 051 351**	**-**	**100.0**

Source: Prepared by the authors.

9.7 IMPLEMENTATION AND QUALITY CONTROL

The Brazilian NFI is coordinated by the SFB through the General Coordination on Forest Inventory and Information, which is responsible for planning, contracting services, training, quality control, management of botanical identification, data processing and analysis, and production and dissemination of results by state. In the state of Santa Catarina, the NFI is supported by the state government and coordinated by the University of Blumenau (FURB) (Vibrans *et al.*, 2010) using the same national methodology. The first cycle was completed and measurements for the second cycle have already started.

Implementation is done on a state-by-state basis and services are contracted through tenders for data collection in areas called lots, which are generally smaller than a state and whose size varies depending on the availability of financial resources. The main reference for the implementation of data collection is the NFI field manual (SFB, 2019c), which contains detailed information on the NFI methodology and the protocol for data collection. Following the hiring of firms, the SFB conducts a training course for the field teams, which lasts about eight days and is led by a team of experienced trainers.

Some 500 people have already been trained through this programme. Participating in the training is a prerequisite for working in the NFI field teams, each of which is composed of five people. Once hired, the firm presents a detailed plan of the logistics and the time needed to collect field data.

Quality control is performed by an SFB team and consists of both field and office activities. In the field, the SFB visits the field teams at the start of their data collection and, whenever possible, a second visit is conducted during the contract period. In addition to verifying working conditions, performance and compliance with the field manual during visits to the field teams, data are collected in the SUs that have been already measured, for comparison with the data collected by the hired team and an evaluation using indicators and verifiers. Approximately 3 percent of the total number of SUs is assessed.

The botanical samples collected by the teams are also subject to quality control upon arrival at the herbarium, where the quality of each sample, its drying conditions, preparation and preservation are assessed. The evaluation criteria consist of a specific form for this purpose and statistics are generated periodically for each team.

The company enters the field data directly into the NFI database. At the office, the SFB team also verifies the data through a consistency analysis, comparing the data entered in the system and the digitised field forms, in order to reduce gaps and inconsistencies.

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TABLE 9.8

Average volume and biomass stocks for some forest types in Brazilian biomes

Forest type	Biome	Number of sampling units	Volume (m^3/ha)	Biomass (t/ha)
Dense ombrophilous forest (FOD)	Amazon	707	355.92 (±4.24)	267.56 (±6.45)
Open ombrophilous forest (FOA)	Amazon	440	342.92 (±6.53)	230.06 (±6.53)
Deciduous seasonal forest	Amazon	191	49.4 (±11.31)	72.14 (±11.31)
Semi-deciduous forest	Amazon	66	315.94 (±11.07)	193.25 (±11.07)
Forest Campinarana	Amazon	32	265.15 (±16.82)	168.48 (±16.82)
Shrub-steppe savannah	Caatinga	680	16.66 (±9.11)	9.01 (±9.11)
Forest savannah	Cerrado	1 783	53.37 (±3.54)	33.31 (±3.54)
Dense ombrophilous forest (FOD)	Atlantic Forest	185	68.23 (±9.84)	68.5 (±9.84)
Mixed ombrophilous forest (FOM)	Atlantic Forest	190	211.15 (±8.28)	11.86 (±13.41)
Semi-deciduous seasonal forest	Atlantic Forest	192	32.96 (±13.41)	59.91 (±13.41)
Deciduous seasonal forest	Atlantic Forest	36	45.56 (±50.14)	35.02 (±50.14)
Semi-deciduous seasonal forest	Pampa	30	84.09 (±33.73)	46.07 (±33.73)
Tree steppe	Pampa	117	105.73 (±17.99)	57.70 (±17.99)

Note: ± relative error in parentheses.
Source: Prepared by the authors.

TABLE 9.9

Growing stock in volume, estimated from National Forest Inventory data for all Brazilian biomes

Biome/specific type	Volume		Biomass	
	Million cubic metres	Percent	Million tonnes	Percent
Amazon	109 155.15	90.5	77 412.20	90.5
Caatinga	1 092.32	0.9	714.79	0.8
Cerrado	4 993.23	4.1	3 341.15	3.9
Atlantic Forest	1 508.29	1.3	1 274.86	1.5
Pampa	273.60	0.2	158.22	0.2
Pantanal	569.45	0.5	393.34	0.5
Planted forests	2 958.50	2.5	2 218.88	2.6
TOTAL	**120 550.54**	**100.0**	**85 513.44**	**100.0**

Source: Prepared by the authors.

9.8 OTHER RELEVANT ATTRIBUTES AND VARIABLES

The field data collected in the NFI in Brazil comprise a set of 180 variables that can be classified as biophysical, socio-environmental, administrative, geospatial and photographic. The field variables collected comprise the NFI database on various forest-related attributes and, in addition to those already mentioned, include variables related to socio-environmental interviews that are conducted during field data collection and botanical identification of species in herbaria.

The collection of botanical material samples of the species found in SUs is an important guideline for a megadiverse country where natural forests correspond to 500 million hectares (SFB, 2019d) and the number of tree species can reach the tens of thousands (ter Steege *et al.*, 2013). Species identification by common name is very difficult and is not suitable for producing reliable information on species diversity or for developing biodiversity-related applications. Thus, field teams collect botanical samples, prepare them and send them to one of the NFI's partner herbaria. About 20 herbaria participate in the NFI, receiving the samples, assessing their quality and identifying them scientifically. The results of the identification are sent to the SFB and become part of the database for each tree, thus making it possible to generate lists of species as a significant result. Botanical samples of approximately 120 000 trees have been collected already, resulting in the identification of 3 371 tree species. Fertile botanical samples are included in the herbarium collections and are also digitised and made available by Reflora, the electronic herbarium of the Rio de Janeiro Botanical Garden, which is also a partner institution of the NFI (Canteiro *et al.*, 2019). The SFB provides support to the herbaria, including the hiring of taxonomists and support for botanical family experts to also visit the herbaria and collaborate on species identification.

This has been one of the NFI's valuable collaborations for improving the knowledge of Brazil's flora; in addition, due to the systematic distribution of sampling units throughout the territory, the number of new species has increased in all regions.

In the context of the NFI, a socio-environmental component was designed to obtain information on the importance of forests for people. Field teams are trained to conduct four interviews in the vicinity of each cluster in randomly selected households within a 2 km radius from the sampling point. The questionnaire is designed to elicit information on the use of wood and non-wood forest products and environmental services, the most commonly used species, individual perceptions of the importance of forests and the demand for forest plantations. Some 28 000 people, including men and women of different ages, have already been interviewed to gather information on the importance of forests for people. Despite specific instructions to the field teams to seek a gender balance, the results show that 37.13 percent of the people were women and 62.87 percent men (out of a total of 27 086 individuals). This result may have several explanations, from women not being found at home at the time of the interview, to local cultural reasons for not being interviewed. Nevertheless, this is considered a good result, which will provide more insight into the differences in perception between women and men regarding the importance of forest resources. This is a unique dataset that may indicate priorities for forestry research and policies that are more closely linked to local demands and appreciation of forests.

Other activities are under development as part of the Brazilian NFI project, including the component of landscape sampling unit analysis, developed by Embrapa Forestry. The classification and interpretation of satellite images of SUs measuring 10 km by 10 km and randomly distributed over the NFI grid produce information and indicators on fragmentation and forests in riparian zones (Rosot *et al.*, 2018), among others. About 400 SUs were processed for the southern regions of the country and the Atlantic Forest biome. A pilot study was conducted to refine the information on planted forests in the state of Paraná. Planted forests occupy barely 1 percent of the national territory and the information obtained from the standard grid is insufficient for a good representation, especially in the case of small areas of planted forests. The study proposes the combination of satellite imagery to guide data collection in planted forests in a way that is integrated with the standard survey already conducted. In addition to this, the SFB has supported research groups in the development of new allometric equations in the different biomes.

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9.9 FUTURE PROSPECTS

The main challenge for the NFI is to complete the data collection nationwide for the current cycle. The actions carried out thus far have consolidated capacity development, progressed toward institutionalizing the NFI, and established a qualified team to manage the NFI. However, it is essential to guarantee regular and sufficient public funding in order for the NFI to be a continuous programme.

Data collection in the Amazon is also a challenge, both because of the difficulties of access and the characteristics of the forest, in terms of the number of trees, tree height and number of species. However, the experience gained to date shows that adapting to the working conditions in the region is possible and that planning can always be improved. Other future prospects are as follows:

- Development of NFI data applications integrated with existing programmes and policies, as a strategy to strengthen it as a state programme that should be permanent and continuous. This approach has already made progress on some issues, such as climate change and sustainable forest management, which require further integration. There are prospects for broadening applications to issues such as forest restoration and payment for environmental services and subnational applications.
- Expansion of data access for research and educational institutions, stimulating the production of information and knowledge beyond the basic results already offered by the NFI.
- Adjustment of the methodology for the second cycle, introducing new field and remote sensing technologies, in order to optimize human and financial resources, as well as time commitment. Consideration should be given to pre-stratification options and further integration with newly emerging issues and public policies, with the aim of obtaining results for different societal stakeholders and at multiple scales.

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Chapter 10

CHILE

NATIONAL FOREST INVENTORY OF CHILE

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10.1 HISTORICAL OVERVIEW OF NATIONAL FOREST INVENTORIES IN CHILE

Since the 1980s, Chile has been implementing permanent forest inventory techniques. However, a ground-breaking effort occurred much earlier in 1944-45 when the Chilean government, in cooperation with the United States Department of Agriculture Forest Service, launched the project "Forest Resources of Chile: Basis for Industrial Expansion" (Haig *et al.*, 1946). This inventory was the first initiative of its kind in Chile and Latin America, thus prompting a major development in forest inventory techniques, such as the use of aerial photographs as a basis for mapping, and capacity development for forest-related professionals. Among other positive effects, this initial inventory highlighted serious concerns about forest sustainability at the time. Unfortunately, this initiative was not implemented to provide adequate forest monitoring and there were no efforts to provide a continuous forest inventory at the time.

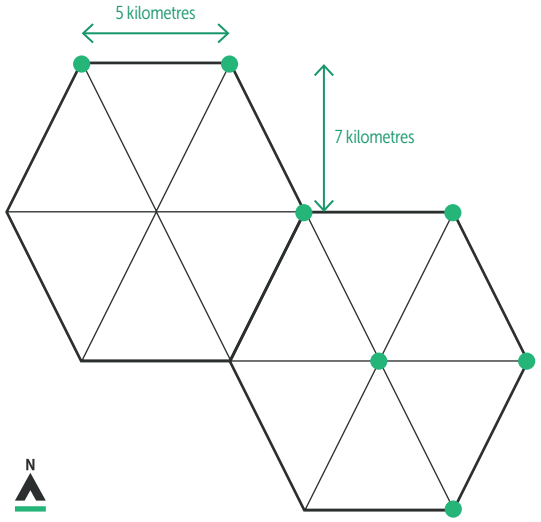
The focus of the 1944 forest inventory was on wood supply and potential production, given the state and condition of the forests at that time. Today, the paradigm of reporting only on the growing stock has shifted to a multifunctional approach to address the sustainability of the forest ecosystem. This shift started after the publication of the report *Our Common Future* (more commonly referred to as the Brundtland Report) by the World Commission on Environment and Development (1987) and the Earth Summit held in Rio de Janeiro in 1992. All of the existing conventions and agreements are the result of that process, including the United Nations Framework Convention on Climate Change (UNFCCC), the Convention on Biological Diversity (CBD) and the various forest agreements such as the Montréal Process, the Helsinki Process (now called the Ministerial Conference on the Protection of Forests in Europe), among others.

In fact, these organizations regularly request countries to provide data and information related to the ecological, economic and social problems related to their forest resources. Given the wide range of information required, it is clear that a large-scale forest ecosystem inventory is needed at national level. Chile's National Forest Inventory (NFI) began officially in 2001 and has continued to date with a periodicity of four years. Each NFI cycle and its dynamics are described in Table 10.1.

The NFI is based on a two-stage design with infinite population on a systematic triangular grid of 5 kilometres (km) by 7 km, with sampling units in clusters of three concentric nested plots where each cluster represents 1 hectare (ha), as shown in Figure 10.1 (INFOR, 2018).

FIGURE 10.1

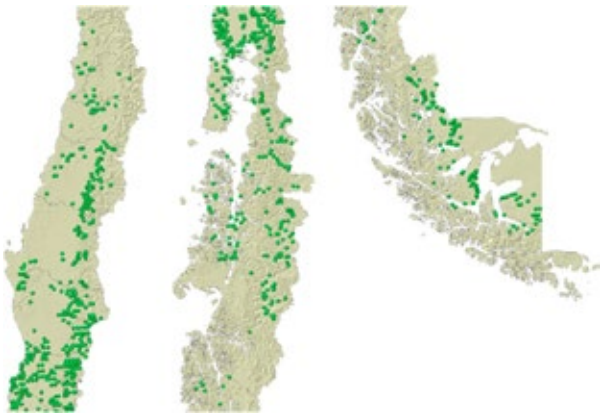
National Forest Inventory sampling design



Source: **Martin, M.C.** 2009. *Inventario de los ecosistemas forestales: Manual de operaciones en terreno.* Santiago, Forestry Institute.

FIGURE 10.2

Distribution of sampling units in clusters across the country for the National Forest Inventory



The boundaries shown and the names and designations used on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any countries, territories, cities, areas, authorities, or delimitation of their frontiers or boundaries. Dotted lines on maps represent approximate boundaries for which there may not yet be full agreement.

Note: Divided into three sections from left to right for space reasons.

Source: **INFOR (Forestry Institute)**. 2018. *Los recursos forestales en Chile. Informe final – Inventario continuo de bosques nativos y actualización de plantaciones forestales.* Santiago.

10.2 TERMS AND DEFINITIONS RELEVANT TO THE IMPLEMENTATION OF THE LATEST NATIONAL FOREST INVENTORY

Table 10.2 describes the most relevant terms applied in the NFI, according to the national definitions set out in the Law on Native Forest Recovery and Forestry Development (Law 20283, 2008). The definition of forest is also considered in the National Greenhouse Gas Inventory and the Reference Level of the Reducing Emissions from Deforestation and Forest Degradation (REDD+) mechanism.

TABLE 10.1

Historical overview of national forest inventories in Chile

Inventory cycle	Implementation period	Scale	Sampling design	Number of sampling units
NFI 1	2001-2009	National	Systematic/ clusters	352
NFI 2	2010-2014	National	Systematic/ clusters	1 109
NFI 3	2015-2019	National	Systematic/ clusters	1 109

Source: Prepared by the authors.

10.3 SAMPLING DESIGN

The Chilean NFI employs a classic two-stage sampling for an infinite population organized geographically in clusters in a systematic grid of 5 km by 7 km in a north–south and east–west orientation, with the shortest distance applied to east–west. The sampling unit is a cluster of three nested and concentric circular units of 500 square metres (m²) (Figure 10.1). The entire country, including the islands of the southern archipelagos, comprises the systematic grid with geographically permanent positions. The points that fall into the "forest" category definition are selected annually in a number of sampling units depending on the budget available each year, with the aim to complete the entire country within a four-year cycle.

Figure 10.2 presents the grid that is currently measured and Table 10.3 details the number of sampling units in each administrative region.

TABLE 10.2

Summary of definitions used to implement the National Forest Inventory

Term	Definition	Variables and thresholds
Forest	An area of a minimum of 5 000 m^2 covered with trees with a potential tree height of more than 2 m and a canopy greater than 25% and 10% for Mediterranean and semi-arid zones, respectively.	Area: 0.5 ha Potential height: 2 m Canopy: 25% and 10%
Other wooded land	n/a	
Other land	n/a	
Volume	Growing stock of the stem of trees with a diameter at breast height (DBH) greater than or equal to 8 cm, including bark and excluding the stump.	DBH with bark: 8 cm
Biomass	All organic matter produced as a result of the photosynthesis process; above- and below-ground biomass is recognised, including coarse and fine woody debris on the soil surface.	DBH with bark: greater than or equal to 4 cm Coarse debris diameter: greater than 10 cm Fine debris diameter: smaller than 10 cm

Note: n/a: not applicable.
Source: **Chile (Republic of)**. *Law No. 20283. Law on Native Forest Recovery and Forestry Development*, 2008.

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TABLE 10.3

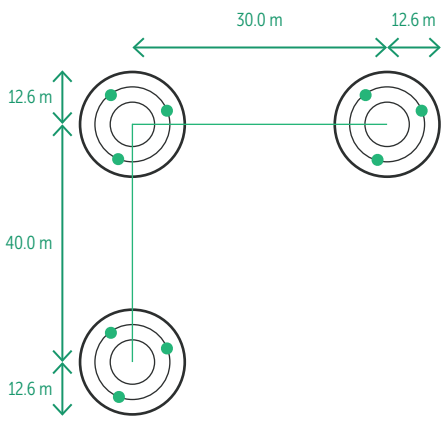
Sampling design characteristics

Name of the region	Total native forests area (1 000 ha)	Number of sampling units			Total number of sampling units / (section)
		Forest	Other wooded land	Other land	
Coquimbo	3.5	-	-	-	5 (1)
Valparaíso	95.4	-	-	-	24 (1)
Metropolitan	93.5	-	-	-	20 (1)
O'Higgins	118.0	-	-	-	31 (1)
Maule	370.3	58	-	-	72 (1)
Bío Bío	786.2	52	-	-	80 (1)
Araucanía	908.5	104	-	-	133 (1)
Los Ríos	850.0	134	-	-	149 (1)
Los Lagos	2 758.8	114	-	-	267 (2)
Aysén	4 814.0	97	-	-	147 (2)
Magallanes	2 625.5	92	-	-	181 (3)
Total	**13 424.0**	**651**	**-**	**-**	**1 109 (-)**

Source: Prepared by the authors.

FIGURE 10.3

Design of the sampling unit used to collect National Forest Inventory data



Source: **Martin, M.C.** 2009. *Inventario de los ecosistemas forestales: Manual de operaciones en terreno.* Santiago, Forestry Institute.

10.4 SAMPLING UNIT DESIGN

The field sampling unit corresponds to a cluster of three concentric, nested circular units as shown in Figure 10.3 below. Information related to the sampling unit is available in more detail in the NFI field operations manual (Martin, 2009).

The nested arrangement of each circular sample consists of three fixed-radius concentric rings associated with tree sizes, specifically, the diameter at breast height (DBH). Thus, trees with DBH greater than or equal to 25 cm are measured within the circle with a radius of 12.63 m; trees with DBH greater than or equal to 8 cm are measured within the circle with a radius of 6.23 m; and trees with DBH greater than or equal to 4 cm are measured within the circle with a 3-metre radius.

The following variables are measured in the field in the aforementioned sampling units. They are arranged in hierarchical order from smallest to largest in terms of spatial scale.

Measurements at tree level

Measurements of the stem and crown include the following: species identification, DBH, diameter at the beginning of the live crown, diameter at one-third of the total height, stump diameter, stem shape, stem quality, total height, commercial height, bark thickness, health status, type of damage or disease, causal agents, crown diameter, crown dominance, crown health and social position of the crown. In addition, tree cores are taken from a subsample at DBH to estimate annual growth. Finally, the trees' development status and vigour are determined and their function as a bait or nest tree is recorded. All trees, whether dead or living, are measured and recorded.

Measurements at the level of trees and their neighbours

These measurements focus on individual trees and their immediate competitors, as well as recognisable elements such as competition or mutualism and growth capacity. For this purpose, a record is made of whether there is silvicultural management, its type and intensity, its position relative to its neighbours, its origin (seed or vegetative), geomorphological elements and

signs of natural or artificial disturbances, erosion, drainage, endangered flora, civil works, areas of religious interest or elements of ethnic interest.

Given the design (Figure 10.3) in which the centre of each circular sampling unit can be connected with a line segment, oriented north–south and east–west, these lines are used as line sampling to estimate coarse woody debris and the imaginary line corresponding to the 2 m radius is used for fine woody debris.

Measurements at stand level

The cluster centred on plot 1 (vertex plot) is used as an indicator of the dynamics of the sampling unit's immediate surroundings. These include soil variables such as pH, depth, humus and leaf litter depth, structure, moisture condition, evidence of earthworms or soil microfauna, roots, rootlets and mycorrhizae, degree of compaction and erosion. In addition, a general description regarding possible anthropogenic influences or disturbance leading to degradation, and elements of the state of biotic, abiotic, cultural-ethnic and social components are also recorded. Regeneration is characterized using plot 1 of the cluster, describing it in terms of species and in four strata from 0 m to 1.3 m in height.

Measurements at landscape level

Biological diversity as a source of life support for the ecosystem is monitored using hexagonal units of 269 000 ha, which contain 50 to 70 clusters within their boundaries. In total, 52 such units are identified throughout the country, located in areas that have forest in accordance with the definition. Three of these units are measured per year and to date seven units have been measured. Information about plants, mammals, arthropods, reptiles, birds and fungi is collected in these units.

10.5 LAND AREA AND BIOMASS CALCULATION

Chile has had a land use monitoring system since 1997, implemented by the Chilean forestry service, the National Forestry Corporation, an institution under the Ministry of Agriculture. This land use monitoring system is based on the methodological approach developed by the Center for Phytosociological and Ecological Studies (Centre d'Etudes Phytosociologiques et Ecologiques in French), known as the land use classification map (carta de ocupación de tierras – COT, according to its acronym in Spanish) (Etienne and Prado, 1982). This consists of a wall-to-wall approach based on the use of medium-resolution satellite material; namely, the Landsat sensor in its different platforms and according to its availability. The land use change monitoring is carried out every two to four years. Table 10.4 below indicates the land areas of different types of land use according to the classes defined by the Global Forest Resources Assessment (FRA) in the 2015 country report.

Volume and biomass stocks of the country's forests are estimated through the NFI under the responsibility of the Forestry Institute (INFOR), an agency of the Ministry of Agriculture dedicated to forestry research.

The calculation of the volumes associated with the different types of forests in the country is carried out by applying volume functions per species at tree level; this is added to the circular sampling plot that corresponds to each cluster, and then expanded over the hectare according to expansion factors defined for the radius of each concentric circle, in accordance with the size of each tree. The results per sampling unit (cluster) are obtained from the average of the corresponding plots. Given the availability of more than one volume function per species (Table 10.5) and in order to identify the most appropriate one, the approximate volume is calculated using a B-spline function that serves

TABLE 10.4

Land area by land use class according to Global Forest Resources Assessment classification

Land area (in thousands of hectares) by land use class					
Native and planted forests	Other wooded land	Other land	Water bodies (inland)	Not recognised	Total
16 231.0	13 080.9	43 786.5	1 229.2	1 367.4	**75 695.0**

Source: Prepared by the authors.

as a guide to identify the best volume function to apply for each species in each plot.

Biomass is estimated using two complementary methods. One corresponds to the use of allometric functions available by species (Table 10.5) and the other involves the conversion of tree volume to biomass, using density data in tonnes per cubic metres (m³). The use of density is only applied in the absence of a biomass function (INFOR, 2018).

All NFI data are managed in a data model designed as a relational model and managed through the database engine Microsoft SQL Server; the spatial portion of the NFI is managed through ArcGIS and, at various intermediate stages, free software such as R, Python, QGis and SAGA is used.

The inventory processing is programmed using procedures stored in SQL and free C++ routines (GNU Compiler Collection) and the results are generated in output format using the Microsoft Report Builder application.

10.6 RESULTS OF THE LATEST NATIONAL FOREST INVENTORY

The results obtained from the last inventory cycle (2018) include all of Chile's forests, with actual measurements of the forests located on the islands of the country's southern archipelago (INFOR, 2018).

The country's total growing stock (Table 10.6) amounts to 3 652.4 million cubic metres of solid poletimber without bark, with an accuracy of 11 percent; the most notable administrative regions include Los Lagos with 649.3 million cubic metres; Aysén with 1 594.3 million cubic metres; and Magallanes with 651.6 million cubic metres. These regions have such magnitudes of stock due to their large expanses of forest cover, with 2.75 million hectares in Los Lagos region, 4.81 million hectares in Aysén region, and 2.62 million hectares in Magallanes region. In terms of productivity, the most productive regions are Bío Bío (283.7 m³/ha), Araucanía (252.1 m³/ha), Los Ríos (263.0 m³/ha) and Aysén (235.6 m³/ha) (INFOR, 2018).

TABLE 10.5

Equations used for volume and biomass calculations

Variables	Equation	Reference
Total volume (m^3)	88 individual tree volume functions 11 log volume functions 7 tapering functions 16 growth functions	Drake, Emanuelli and Acuña (2003) Haig *et al.* (1946)
Biomass (kg)	244 biomass functions for native species 112 biomass functions for alien species (41% correspond to above-ground biomass, 13% stemwood biomass, 14% branch biomass, 10% leaves, 14% bark, and the remaining 8% comprise live crown, twigs and roots)	Milla *et al.* (2013)

Source: **Drake, F., Emanuelli, P. & Acuña, E.** 2003. *Compendio de funciones dendrométricas del bosque nativo.* Santiago, National Forestry Corporation and German Corporation for Technical Cooperation (GTZ).; **Haig, I.T., Teesdale, L.V., Briegleb, P.A., Payne, B.H. & Haertel, M.H.** 1946. *Forest resources of Chile as a basis for industrial expansion. Washington DC, United States Department of Agriculture, Forest Service.;* **Milla, F., Emanuelli, P., Sartori, A. & Emanuelli, J. 2013.** *Compendio de funciones alométricas para la estimación de la biomasa de especies forestales en Chile: elemento clave para el desarrollo de la estrategia de bosques y cambio climático (ENBCC).* Santiago, National Forestry Corporation.

TABLE 10.6

Growing stock estimates per region, measured in second cycle

Region	Area (1 000 ha)	Volume (m^3/ha)	Growing stock (1 000 m^3)
Coquimbo	3.5	117.75	412.12
Valparaíso	95.4	35.43	3 380.02
Metropolitan	93.5	41.68	3 897.08
O'Higgins	118.0	74.32	8 769.76
Maule	370.3	175.52	64 995.05
Bio Bio	786.2	283.78	223 107.83
Araucanía	908.5	252.11	229 041.93
Los Ríos	850.0	263.00	223 550.00
Los Lagos	2 758.8	235.36	649 311.16
Aysén	4 814.0	331.20	1 594 396.80
Magallanes	2 625.5	248.17	651 570.33
Total	**13 424.0**	**-**	**3 652 432.08**

Source: Prepared by the authors.

10.7 QUALITY CONTROL

The quality control established for the inventory comprises the following four aspects.

Staff training

This corresponds to theoretical training of the field crews based on the field operations manual, focusing on their thorough knowledge of the measurement procedures described in the manual. This phase ends with a final examination on content and procedures, with evaluation and grading. In addition, a supervised practical exercise is carried out on training plots that have been previously measured, where the crews practise procedures in the field, resolve issues and make concrete decisions. The measurements collected by the trainees are compared with the reference measurements for evaluation and further improvement.

Data entry validation

The collection of measurement data in the sampling unit is done by recording the data in a data entry system, which includes programmed data entry forms for the various levels of information described in the previous paragraphs. In the case of tree-level data, the diameters are recorded sequentially in terms of height; thus, the diameter of the stump is recorded first, then the DBH, followed by the diameter at one-third of the total height, and so on. As a validation rule, these diameters should not be greater than the previously entered datum; for example, the stump diameter should be greater than or equal to the DBH, the DBH should be greater than or equal to the diameter at one-third height, and so on. The data entry programme applies this type of validation rule to avoid, to the extent possible, any errors in consistency.

Database validation

The data collected by the field crews in the data logger are transferred directly to the database, to different tables according to the design of the inventory data model. The data entered are reviewed for inconsistencies through a detailed examination of the following variables, among others:

- misused units (millimetres instead of centimetres, centimetres instead of metres, etc.);
- input dyslexia (change in the order of numbers, e.g. 26.9 instead of 29.6);
- allometric inconsistencies (DBH–height pairs are compared graphically to detect any inconsistencies);
- diameters and heights that are disproportionate to the overall mean;
- misassigned species, cases of species that do not correspond to the geographical location;
- error in the geographic coordinates of the plot.

Quality control visit

During the measurement cycle, the crews perform a random check of 1 to 3 percent of the measurement plots. Although this is a standard quality control practice, it represents an additional cost that is deducted from the inventory budget. Since these funds could be used to include new sampling points to provide more information, to avoid this expense, the point above on staff training has proven to be more effective as a preventive rather than ex-post measure.

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10.8 OTHER RELEVANT VARIABLES

In addition to the biophysical variables, the NFI includes the collection of variables related to socioeconomic aspects that influence the forest. This consists of a survey of forest owners or users, using the biophysical inventory point grid as a sampling base (Betancourt and Reyes, 2021). On average, about 60 surveys are conducted per year. In addition, the systematic point grid is used to implement biodiversity sampling outside of kingdom Plantae, particularly birds, arthropods, mammals and reptiles (Vergara, Bahamondez and Sagardía, 2021).

10.9 FUTURE PROSPECTS

Future planning can be summarised in two main aspects:

- Make the socioeconomic and biodiversity inventory operational at national level. Given that these monitoring areas have been methodologically and logistically tested and meet all the data and information requirements that were tested in the last cycle, they should now be included as regular NFI activities.
- Promote methodological and technological improvements. The budgetary aspects of the NFI are a permanent issue in each measurement cycle; this requires improving procedures and technologies for capturing, recording and storing data used in the measurements in order to increase or at least maintain the sampling intensity of the NFI, in the interest of resource efficiency.

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NEXT CHAPTER

COLOMBIA

Chapter

COLOMBIA

NATIONAL FOREST INVENTORY OF COLOMBIA

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11.1 HISTORICAL OVERVIEW OF NATIONAL FOREST INVENTORIES IN COLOMBIA

The national forest inventory dates back to 1919, with the enactment of Law 119 of 1919, which ordered the creation of a Forestry Commission whose main mission was to classify and measure the country's forests. However, it was in 1959, when Law 2 of 1959 was passed, that the country was zoned into seven large forest reserve zones and the corresponding forest management plans were ordered to be drawn up.

During the 1960s and 1970s, a series of regulatory and institutional milestones were reached that gave new impetus to the Colombian environmental sector. In 1968, the National Institute of Renewable Natural Resources and Environment (Instituto Nacional de los Recursos Naturales Renovables y del Ambiente in Spanish) was created. In 1974, a new legal framework for environmental matters was defined with the publication of the National Code for Renewable Natural Resources and Environmental Protection (Law Decree 2811 of 1974), under which a number of regional forest inventories concerning forest use and management were carried out; these inventories provided the first statistically based figures on Colombia's forests.

In 1991, the adoption of the new Political Constitution of Colombia laid the foundation for a new institutional framework on the environment. These elements were incorporated into Law 99 of 1993, which created the Ministry of the Environment and reorganised the Colombian environmental sector. The Forest Policy (document CONPES 2834 of 1996) was subsequently approved, which established as a general objective "to achieve a sustainable use of forests in order to conserve them, consolidate the incorporation of the forestry sector into the national economy and improve the population's quality of life" (Ministry of the Environment and DNP, 1996).

In this context, in the year 2000, the Ministry of the Environment together with the Ministry of Agriculture and the National Planning Department approved the National Forest Development Plan (NFDP), which includes the national and regional forest inventory and defines it as "a basic instrument for the management and conservation of forest resources, which allows for the identification of the current supply and its conservation status" (Ministry of the Environment *et al.*, 2000). The NFDP entrusts the following institutions with its implementation: Institute of Hydrology, Meteorology and Environmental Studies (IDEAM), other Environmental Research Institutes (Institutos de Investigación Ambiental – IIA, according to its acronym in Spanish), the Regional Autonomous and Sustainable Development Corporations (Corporaciones Autónomas Regionales y de Desarrollo Sostenible – CAR, according to its acronym in Spanish) and academia.

Parallel to this process and under Decree 1791 of 1996 – Colombia's Forest Harvesting Regime – forest inventories for forest harvesting purposes were carried out across the entire Colombian territory. Although they had different objectives, these inventories provided a documented reference of the structure and composition of forests at the regional level and laid the foundations for forest management processes. However, these initial regional forest inventory exercises were developed with different methodologies, designs, sampling unit (SU) sizes and shapes, varied sampling intensities and different indicators; in the long term, this meant that the information was not comparable and homogeneous, thus limiting the possibility of carrying out comprehensive analyses and generating consolidated statistics and data on the country's forests.

In 2006, in order to respond to the need to monitor and characterize forest ecosystems, IDEAM designed the Forest Monitoring Programme (Programa de Monitoreo y Seguimiento de Bosques). Through this programme, relevant statistical operations were identified for improving knowledge on forest ecosystems, highlighting those of the NFI.

In 2007, IDEAM began the process of building the NFI through a series of regional consultations with CARs, governmental environmental organizations, professionals working on forest-related issues, academia, among others, in order to define the objective and scope of the NFI. In a second phase, a conceptual and methodological design stage of the NFI was initiated in conjunction with the National Administrative Department of Statistics (DANE) and the Ministry of the Environment; this design was validated through three pilot field tests, which provided inputs to validate and adjust the proposed methodology.

In keeping with the above and as a result of the pilot validation exercises and the inter-institutional alliance, the conceptual and methodological framework design of the National Forest Inventory was published in 2009 (IDEAM and DANE, 2009); this document describes the reference elements and requirements for the implementation of the NFI.

Between 2010 and 2013, IDEAM defined an adequate cost structure for the implementation of the NFI and initiated the process of securing funding sources. However, considering that the timeframe for this phase had been planned to be carried out within one year, a series of financial, logistical, technical and operational efforts were required that were not yet available.

As a result, and in order to make progress in securing resources for its implementation, capacity development was initiated in 2013 in collaboration with strategic partners, such as the United States Department of Agriculture Forest Service. Likewise, technical support from the SilvaCarbon programme and the United States Agency for International Development (USAID) resulted in adjustments to the NFI methodological design and the first version of the NFI quality control manual (Barbosa *et al.*, 2014).

Given that the implementation of the NFI seeks the participation of agencies within the National Environmental System (SINA), the development of the first cycle and its field operations was done directly with the IIAs, starting in 2015. With funding from the governments of Germany, Norway and the United Kingdom of Great Britain and Northern Ireland, the implementation of the first NFI cycle began in Colombia's five major natural regions.

11.2 TERMS AND DEFINITIONS RELEVANT TO THE IMPLEMENTATION OF THE LATEST NATIONAL FOREST INVENTORY

The Colombian NFI is defined as the statistical operation through which variables of national interest (forest area, composition, structure, forest diversity, among others) related to Colombia's natural forests are objectively recorded, in order to provide information that is required by different users and that contributes to forest monitoring, to the development of management plans, and to the sustainable management of this resource in Colombia (Colombia, 2017).

In this context, the NFI is governed by the principles established by the National Statistical System (Sistema Estadístico Nacional – SEN, according to its acronym in Spanish) that

guarantee the production and dissemination of the country's official statistics; thus, the NFI must comply with the guidelines established in the Technical Standard for the Quality of the Statistical Process (NTC PE 1000 of 2017), which are defined by DANE as the system's governing body. In keeping with the above, the methodological approach that serves as a basis for the NFI design complies with the principles of objectivity, relevance, flexibility, adaptability, homogeneity, neutrality, accessibility, coherence and transparency, among others (Olarte *et al.*, 2021).

11.3 SAMPLING DESIGN

The following is a general summary of the theoretical concepts of the geostatistical design and the methodology used to develop the implementation plan for Colombia's NFI.

The scope of the NFI consists of the elements to which the results achieved in the sample will be extended. For Colombia's NFI, the scope corresponds to the country's mainland and insular regions, while the target population includes three categories of the total continental land area: natural forest, non-forest and areas with no information.

TABLE 11.1

Summary of the main definitions used by the Colombian National Forest Inventory

Term	Definition	Variables and thresholds
Natural forest	Land occupied mainly by trees that may contain shrubs, palms, *Guadua* bamboo, grasses and lianas, in which tree cover predominates with a minimum canopy density of 30%, a minimum canopy height *in situ* of 5 metres at the time of identification and a minimum area of one hectare. Tree cover of commercial forest plantations, palm plantations and trees planted for agricultural production are excluded (IDEAM, 2019).	Minimum area: 1 ha Canopy cover: > 30% Tree height: ≥ 5 m Exclusions: Tree cover of commercial forestry plantations, palm plantations and trees planted for agricultural production
Stem volume	This is the measure of the amount of solid wood contained in the stem section from the base of the stem to the first branch or fork of the tree or to the beginning of the live crown. It is calculated using the normal diameter (diameter at breast height [DBH]) ≥ 10 cm and the height of the stem (measured from the base of the stem or stem to the beginning of the crown). Includes bark. No limit is set on the diameter of the branch to which the tree forks. It should be noted that if the fork is below 1.3 m, the tree is considered to have multiple stems and, in this case, the number of stems with their respective size category, diameter and height are measured independently.	DBH ≥ 10 cm Stem height: from the base to the first branch of the crown Bark included Branches not included
Total volume	This is the measure of the amount of solid wood contained in the section of the stem from the base of the stem to the apex of the tree with bark. It includes the volume of the stem as described in the previous item.	DBH ≥ 10 cm Stem height: from the base to the first branch of the crown Bark included
Biomass	Woody mass (stem, bark, branches and roots) of trees, palms and arborescent ferns in a vegetation area.	DBH ≥ 5 cm Stem height: from the base to the first branch of the crown Bark, stem, roots, fruits, flowers and branches included
Above-ground biomass	All above-ground living biomass, including stems, branches, bark, seeds, foliage and fruits.	DBH ≥ 5 cm Stem height: from the base to the first branch of the crown Bark, stem, fruits, flowers and branches included

Source: Prepared by the authors with data from **IDEAM (Institute of Hydrology, Meteorology and Environmental Studies)**. 2019. *Proporción de la superficie cubierta por bosque natural en el territorio continental e insular. Proyecto Sistema de Monitoreo de Bosques y Carbono* (SMByC). Bogota.

The subpopulations of interest are the country's natural regions: Andes, Caribbean, Pacific, Orinoquía and Amazonia.

The NFI will be implemented in five-year cycles through annual surveys, in which new measurements will be taken in 20 percent of the sampling units. The reference period of the NFI measurements for the first cycle is from 2015 to its expected completion in 2022, considering that the effective implementation period has been affected by public order problems and the global health emergency.

Sampling is probabilistic given that the sampling units have a known probability greater than zero in order to be selected. The sampling design is post-stratified because strata or population partitions (forest, non-forest, no information and natural regions) are considered after the survey (Olarte *et al.*, 2021). The land area that corresponds to this post-stratification in each subpopulation is presented in Table 11.2.

TABLE 11.2

Land area of the subpopulations of interest per post-stratum category

Region	Natural forest (ha)	Not natural forest (ha)	No information (ha)
Amazonia	39 661 290	6 194 338	2 543
Andes	10 549 240	17 528 775	1 108 559
Caribbean	1 723 966	13 720 193	5 996
Orinoquía	2 144 514	14 688 074	30
Pacific	5 233 267	1 152 722	335 980

Source: Prepared by the authors.

The sampling frame consists of areas with imaginary boundaries. The areas were drawn systematically and consist of square polygons of 24 kilometres (km) by 24 km. A random probability sample was selected, thus the NFI design consists of a post-stratified simple random cluster sampling. The clusters correspond to the cross arrangement of the five circular subplots (see section 11.4).

For the sample size calculation, the following three variables – considered the most technically relevant by the NFI team as guiding variables – were analysed: diameter at breast height (DBH), basal area (BA) and volume.

To define the sample size for the NFI, the volume variable and an estimated coefficient of variation of 5 percent were selected, which resulted in a sample size of 1 479 sampling units or clusters. These were distributed in each of the five natural regions of Colombia, as shown in Table 11.3.

TABLE 11.3

Sample size per region

Region	Number of sampling units
Amazonia	595
Andes	379
Caribbean	200
Orinoquía	218
Pacific	87
Total	**1 479**

Source: Prepared by the authors.

A grid of square polygons measuring 12 km by 12 km is established within the main grid of 24 km by 24 km (Figure 11.1) to provide additional alternatives in the location of sampling sites (statistically determined as oversampling). Based on its location, this grid is associated with the main grid and is designed with the same original parameters.

Random points are generated within each element of the 12 km by 12 km grid in order to select the simple random sample. To ensure that the random points are within Colombian territory, the selection is made only on the grid-cells that have 100 percent mainland coverage. The result is a map of points from which one point is randomly selected for each grid-cell of 24 km by 24 km, until completing the 1 479 points defined as the sample size of the NFI. Three additional points per grid-cell are selected for the oversample, which have the same original simple random sampling design. Figure 11.2 shows a summary of the process.

FIGURE 11.1

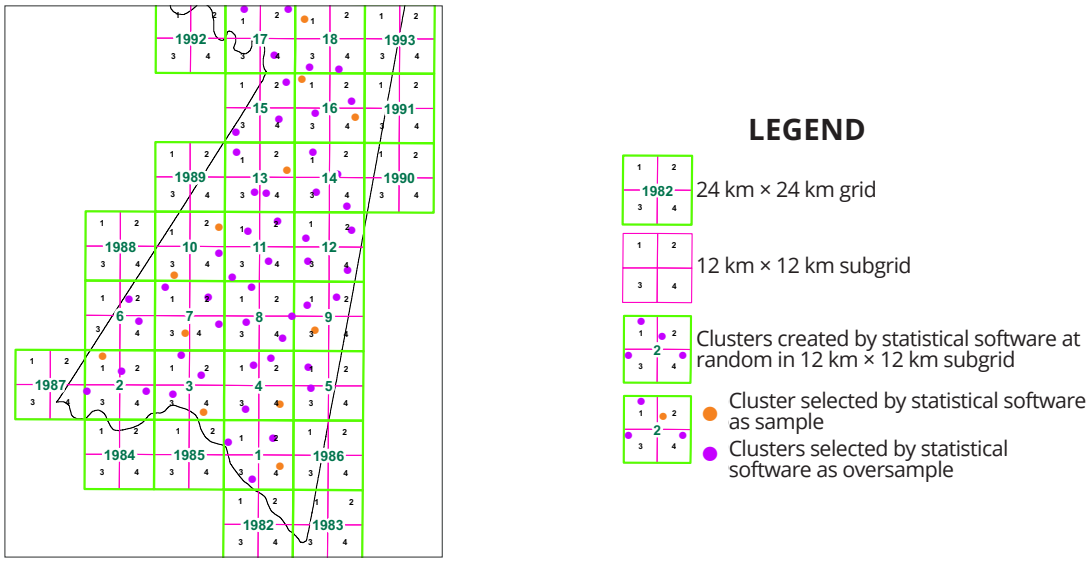
Grid of equidistant points of 24 kilometres by 24 kilometres for the mainland and insular regions of Colombia

The boundaries shown and the names and designations used on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any countries, territories, cities, areas, authorities, or delimitation of their frontiers or boundaries. Dotted lines on maps represent approximate boundaries for which there may not yet be full agreement

Source: **Olarte Villanueva, C.P., Merchán López, O.F., Linares Prieto, R., Quintero Cardozo, F., León Cruz, R., Rodríguez León, A. & Montealegre, J.O.** 2021. *Marco rector para la implementación del Inventario Forestal Nacional.* Bogota, Institute of Hydrology, Meteorology and Environmental Studies.

FIGURE 11.2

Random points for each grid level



Source: **Olarte Villanueva, C.P., Merchán López, O.F., Linares Prieto, R., Quintero Cardozo, F., León Cruz, R., Rodríguez León, A. & Montealegre, J.O.** 2021. *Marco rector para la implementación del Inventario Forestal Nacional.* Bogota, Institute of Hydrology, Meteorology and Environmental Studies.

11.4 SAMPLING UNIT DESIGN

The sampling units consist of a cluster of five circular subplots (called SPFs) arranged in a cross shape, where four subplots are 80 m away from the central plot. Each subplot has a radius of 15 m, equivalent to a total area of 707 m^2 (Figure 11.3).

Among other technical criteria, this design was developed to withstand sampling error in terms of the estimated coefficient of variation of 5 percent and 95 percent confidence level, as well as for cost-efficiency reasons. The central plot of each cluster corresponds to the location of the sampling sites that were designed, calculated and geographically located for the NFI.

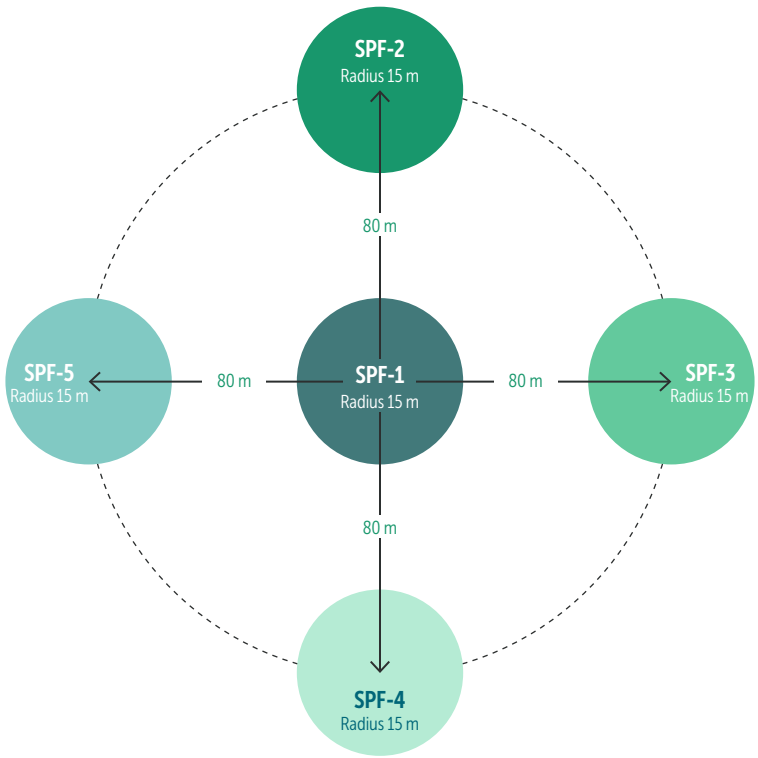
Four types of observation units were established, according to the size of the trees being measured (see Table 11.4 and Figure 11.4).

11.5 LAND AREA, VOLUME AND BIOMASS CALCULATION

Data on the land area that is covered by natural forest are obtained from the forest/non-forest cover map for Colombia, produced by IDEAM's Forest and Carbon Monitoring System (Sistema de Monitoreo de Bosques y Carbono – SMByC, according to its acronym in Spanish); it is in raster format with a pixel size of 30.26 m by 30.72 m and a MAGNA-SIRGAS EPSG:3116 projection (compatible with a scale of 1:100 000). This map is produced from the interpretation of satellite images, that is, by identifying and assigning to each pixel or observation unit a specific classification: forest, non-forest or no information. It uses Landsat images (TM, ETM+ and OLI sensors) taken between 1 January and 31 December each year, supplemented in some cases with other medium-resolution optical and radar images from the same period (IDEAM, 2019a).

FIGURE 11.3

Configuration of the sampling units or clusters for the National Forest Inventory



Note: Each subplot is represented as "SPF."

Source: **IDEAM.** 2021. *Manual de campo Inventario Forestal Nacional, Versión 5.2.* Bogota.

TABLE 11.4

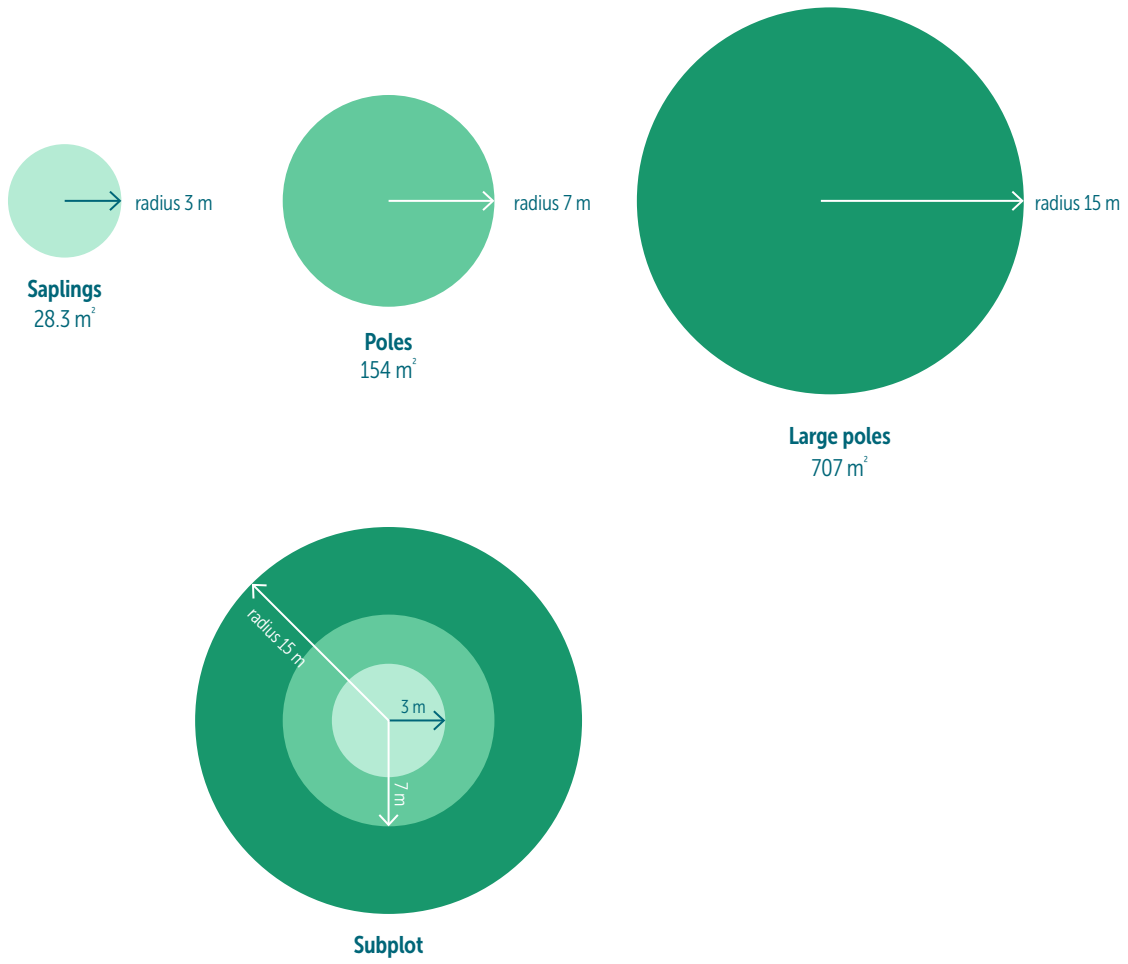
Observation units for the National Forest Inventory

Seedlings	Saplings	Poles	Large poles
Trees with diameter at breast height (DBH) less than 2.5 cm. Seedlings shall be measured in five subplots located at a distance of 7.5 m and at 45° from the centre of each subplot. The seedling subplots have a radius of 1.5 m, equivalent to 7.07 m^2 each, for a total of 35.34 m^2.	Trees with a DBH greater than or equal to 2.5 cm and less than 10 cm. Saplings shall be measured in five nested and concentric subplots, with a radius of 3 m each, equivalent to 28.27 m^2, for a total of 141.35 m^2.	Trees with a DBH greater than or equal to 10 cm and less than 30 cm. The poles shall be measured in five nested and concentric subplots, with a radius of 7 m each, equivalent to 154 m^2, for a total of 770 m^2.	Trees with a DBH greater than or equal to 30 cm. The large poles shall be measured in the five subplots of 15 m radius, equivalent to 707 m^2 each, for a total sampling area of 3 535 m^2 per cluster.

Source: Prepared by the authors.

FIGURE 11.4

Subplot configuration



Source: **Olarte Villanueva, C.P., Merchán López, O.F., Linares Prieto, R., Quintero Cardozo, F., León Cruz, R., Rodríguez León, A. & Montealegre, J.O.** 2021. *Marco rector para la implementación del Inventario Forestal Nacional.* Bogota, Institute of Hydrology, Meteorology and Environmental Studies.

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According to the definition of natural forest, an area is considered as forest if, among other features, the natural woody vegetation cover has a minimum land area of 1 hectare; therefore, for the sake of consistency, this value is established as the minimum mapping area.

A semi-automated methodology is applied to image processing, following the protocol for digital image processing for the quantification of deforestation in Colombia (Galindo *et al.*, 2014) and using the processing algorithms defined by the SMByC (available at https://github.com/SMByC). The resulting information is provided through the indicator of the land area covered by natural forest (IDEAM, 2019), which is reported at three levels: i) national: mainland and insular regions (San Andrés and Providencia) of Colombia; ii) departmental: departments of the politico-administrative division of the mainland and insular territory; and iii) per jurisdiction of the CARs.

Different indicators were derived from the field data collected by the NFI, namely, forest ecological structure, tree biodiversity, above-ground biomass (AGB), carbon, and floristic and dasometric indicators.

Considering that Colombia is in the process of implementing the first NFI cycle, there are no models yet for estimating volumes and these are calculated directly through the formulas indicated in the NFI framework document (Olarte *et al.*, 2021). It is expected that specific models per biogeographic region, forest type, cover type and species will be available for future NFI implementation cycles. Table 11.5 presents the main equations applied in the first cycle.

Since the applicable range of the allometric equation presented in Table 11.5 is from 5 cm to 212 cm DBH, trees with diameter less than 5 cm were excluded from the calculations, while trees exceeding the maximum diameter were assigned the maximum value (212 cm) in order to estimate their AGB.

Once the aggregated estimates were made per cluster, the values were extrapolated to the hectare (tonnes per hectare [t/ha]). With the latter value, below-ground biomass (roots) was estimated using the following equation from Cairns *et al.* (1997):

$$BGB = exp\,(-1.085 + 0.9256\,log(AGB))$$

Where BGB is below-ground biomass (t/ha) and AGB is above-ground biomass (t/ha).

TABLE 11.5

Equations used for volume and biomass calculations

Variables	Equation	Reference
Total volume per tree (m^3)	$VTi = ABi \times HT \times ff$ Where: *ABi*: basal area of the tree (in m^2) *ff:* form factor (form factors available in the literature are used according to the identified species) *HT:* total height (in m) *VTi:* total volume of the tree (in m^3)	Linares (2015)
Biomass and stored carbon (t)	Biomass of arborescent ferns $AGB = 4\,266\,348 / \left(1 - (2\,792\,284 \times (exp(-0.313677) \times H))\right)$ Biomass of palms $AGB = exp\left(0.360 + (1.218 \times ln(H))\right)$ Biomass of trees $AGB = 0.0673 \times (G \times DBH^2 \times H)^{0.976}$ Where: *AGB:* above-ground biomass (kg) *DBH:* diameter at breast height *G:* wood density *H:* tree height Carbon $C\ (tonnes)/ha = 0.5\ AGB$ Where: *AGB:* above-ground biomass per hectare (tonnes) *C:* carbon content (tonnes)	Chave *et al.* (2014)

Source: **Chave, J., Réjou-Méchain, M., Búrquez, A., Chidumayo, E., Colgan, M.S., Delitti, W.B.C., Duque, A.,** *et al.* 2014. Improved allometric models to estimate the aboveground biomass of tropical trees. *Global Change Biology,* 20 (10): 3177–3190.; **Linares, R.** 2015. *Guía para el desarrollo de la ordenación forestal integral y sostenible en Colombia.* Bogota, Ministry of the Environment and Sustainable Development.

11.6 RESULTS OF THE MOST RECENT NATIONAL FOREST INVENTORY

As mentioned above, the country is in the process of establishing the NFI baseline, thus to date there are partial results available from the cluster analysis carried out between 2015 and 2019, developed in collaboration with researchers from the National University of Colombia. The indicators reflect the study scope, which corresponds to the country's entire mainland and insular land area.

At the time of publication, 41 percent of the first cycle of Colombia's NFI has been completed, through clusters distributed throughout the country in the five natural regions previously mentioned (Amazonia, Andes, Caribbean, Orinoquía and Pacific). The principal results obtained to date include analyses of the diversity and floristic composition of Colombia's natural forests, as well as data on AGB stock and carbon content. Some of the main results are shown in Table 11.6.

The results presented in Table 11.6 indicate that the Amazon differs in a statistically significant way from the other regions, not only because of the greater abundance of trees per land area, but also due to greater diversity of species.

The Shannon index and Fisher's alpha index are consistent with the previous statement. The high Shannon index value in the Amazon, in relation to the value obtained in the other regions, denotes greater equitability, unlike the other regions whose tree cover has some dominant species; this coincides with the Fisher's alpha index, which confirms a high level of representation for each species present in the Amazon region.

The ten most recorded species are the following: *Oenocarpus bataua*, *Clathrotropis macrocarpa*, *Eschweilera coriacea*, *Euterpe precatoria*, *Tapirira guianensis*, *Virola elongata*, *Siparuna guianensis*, *Socratea exorrhiza*, *Micrandra sprucei* and *Astronium graveolens*. The ten families with most species are: Fabaceae, Rubiaceae, Melastomataceae, Lauraceae, Annonaceae, Euphorbiaceae, Malvaceae, Moraceae, Sapotaceae and Chrysobalanaceae.

Regarding the results obtained for AGB, preliminary results by biogeographic region for the 303 clusters analysed are presented in Table 11.7.

Another noteworthy achievement in the implementation of the NFI is the active participation of the different Indigenous, Afro-Colombian and peasant communities that have settled in the Colombian forest ecosystems and participated as co-researchers in the field surveys. The high participation of women in the Colombian NFI is also worth highlighting: taking into account the professional and administrative staff, crews and co-researchers, the participation has been around 55 percent women and 45 percent men.

TABLE 11.6

Number of species, total and average Shannon index and Fisher's alpha index per biogeographic region of Colombia

Index	Amazonia	Andes	Caribbean	Orinoquía	Pacific
Number of trees	63.68 [A]	19.5 [B]	14.28 [B]	13,26 [B]	25 [B]
	(15.04)	(15.49)	(12.80)	(8.78)	(12.82)
Number of species	33.54 [A]	8.56 [B]	7.15 [B]	6.82 [B]	15.8 [B]
	(8.68)	(6.92)	(5.06)	(4.76)	(8.41)
Shannon	26.19 [A]	6.83 [B]	6.16 [B]	5.71 [B]	13.78 [B]
	(8.29)	(5.81)	(4.40)	(4.16)	(7.58)
Fisher's alpha	78.63 [A]	18.33 [B]	24.74 [B]	15.08 [B]	31.16 [B]
	(58.51)	(15.93)	(23.57)	(11.09)	(15.07)

Note: A and B denote statistically significant differences based on the comparison of means for each index, using the Tukey HSD test. Data in parentheses correspond to the standard deviation. The difference between regions was defined by the Tukey HSD test. Values are presented as average per cluster, considering only individuals with diameter at breast height greater than or equal to 10 cm.

Source: **IDEAM & UNAL (National University of Colombia).** 2021. *Comparación de la diversidad y riqueza de especies entre tipos de bosque y/o regiones biogeográficas: Resultados preliminares*. Bogota.

TABLE 11.7

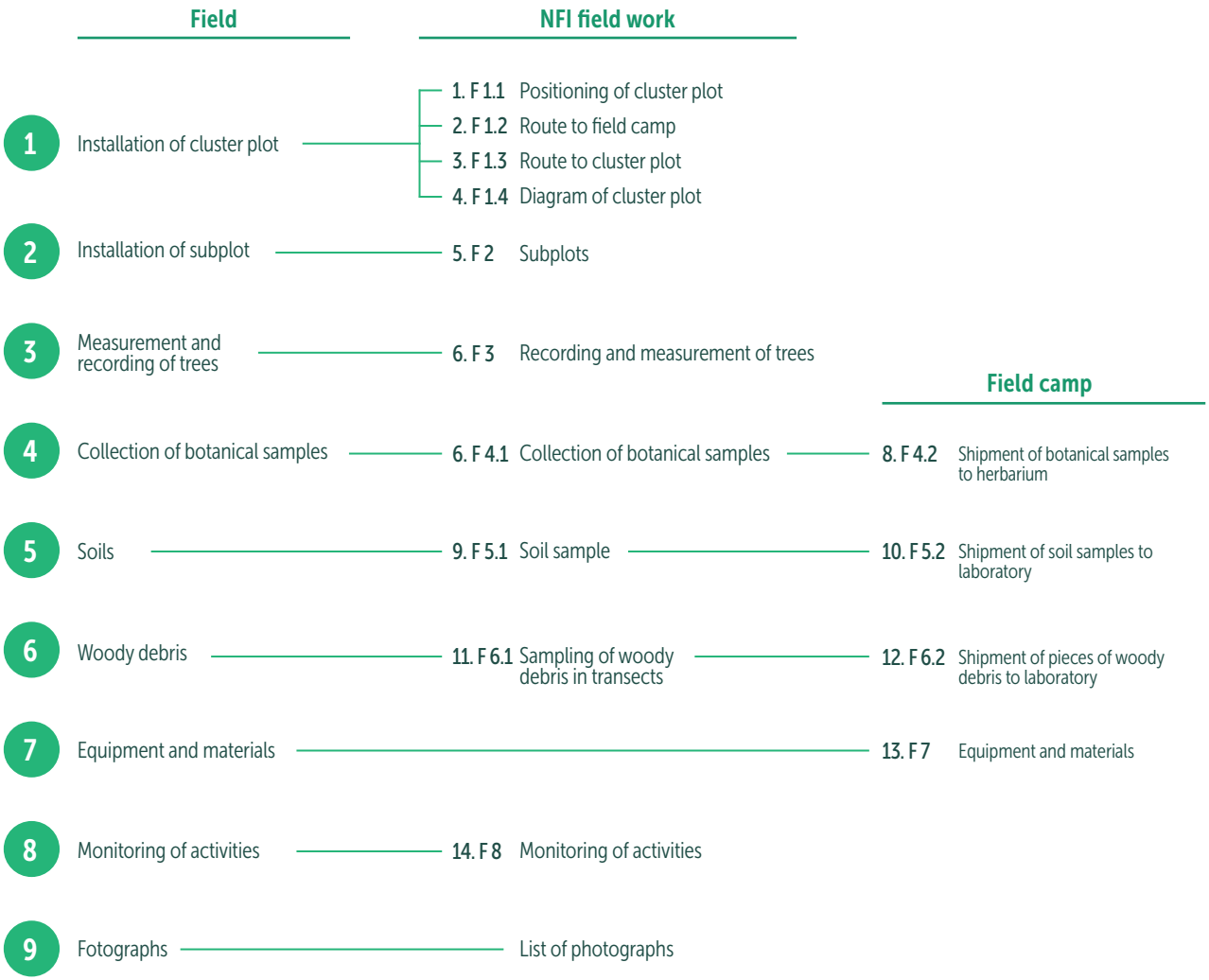
Estimates of total above-ground biomass by biogeographic region

Region	Above-ground biomass (tonnes)	Standard error	Estimated coefficient of variation
Amazon	13 612 000 000	495 237 655	3.64
Andes	3 474 976 614	268 956 877	7.74
Caribbean	1 934 925 255	560 468 683	28.97
Orinoquía	1 412 426 555	275 737 298	19.52
Pacific	2 009 711 667	738 980 445	36.77
National	22 444 040 091	1 119 752 847	4.99

Note: Data are presented in tonnes for comparability with official figures.
Source: **IDEAM.** 2019. *Documento de la revisión, análisis de los reportes y cifras estimadas de carbono para nivel de referencia forestal*. Bogota.

FIGURE 11.5

Sequence of National Forest Inventory field operations



Source: **IDEAM.** 2021. *Manual de campo Inventario Forestal Nacional, Versión 5.2.* Bogota.

11.7 IMPLEMENTATION AND QUALITY CONTROL

In order to ensure the best quality information for the NFI, the use of a standardized, efficient and appropriate methodology for the forest crews to establish the sampling units or clusters is essential. To this end, the NFI field manual provides details on the methodology of field operations and the procedures that field staff must follow in the NFI data collection process.

Figure 11.5 provides a brief description of the methodology used for the field survey, which can be seen in greater detail in the NFI field manual (IDEAM, 2021).

The field operation strategy of the Colombian NFI is structured around the five natural regions and it is designed to be carried out jointly with the institutions that are part of the SINA. Through agreements or contracts that are signed with IDEAM, these institutions carry out NFI coordination, operations and logistics in the field and develop the processes and support required in the preparation and field operation phases; they are also responsible for the necessary agreements with local communities. In the NFI structure, they are called Logistics Operators and are also in charge of hiring staff for field crews.

The NFI has a quality assurance programme to guarantee that the information provided to users is accessible, coherent, comparable, continuous, accurate, timely, transparent, relevant and interpretable, maintaining IDEAMs credibility as a public institution that provides technical and scientific support to the SINA for decision-making. This programme supervises, evaluates and monitors the different activities of the forest inventory to ensure compliance with the desired level of quality by paying attention to each stage of the process. The two components of quality assurance are: i) quality control and ii) quality assessment.

To carry out the quality control and assessment of the information obtained, the NFI has references for each of its processes, such as manuals, guides and templates, which have been designed to ensure that the activities are carried out according to the standards established by IDEAM (Colombia, of 2017) and DANE (DANE, 2017) and that they are always developed, recorded and documented in the same way.

One of the main instruments used in the evaluation and validation of the data collected in the field is the data review manual. This document defines precisely what is meant by "errors or inaccuracies in the data", in order to understand what constitutes an error, as well as the steps to be taken in case errors or inaccuracies are found. In general, quality control during the NFI field operation is structured in several stages (pre-operational, operational and post-operational) and levels (crew officer, supervisors, regional coordinator and NFI leader or IDEAM central coordinator, with the support of the data review team). Another level of quality control is performed by the quality control team, which is distinct from the field operation team. This team is in charge of carrying out control procedures on 7 percent of the clusters of the sample defined for each area, using three types of verification: hot, cold and blind checks.

11.8 OTHER RELEVANT VARIABLES COLLECTED

The Colombian NFI has about 100 variables including dasometric variables (diameter, stem height and total height), floristic composition (family, genus and species), biological characteristics (rarity, endemism), stem quality, vitality, and variables related to soils (bulk density, carbon and fertility) and detritus (fine, coarse, dead standing trees and stumps).

11.9 FUTURE PROSPECTS

The strategic decision-making elements in Colombian forest management are based on existing information and knowledge. Therefore, providing timely, reliable, consistent and comparable information for a better understanding of the state and dynamics of natural forests is a priority for the Colombian State, which has advanced in this effort since 2015 with the implementation of the Colombian NFI baseline.

Considering the characteristics of the NFI's statistical operation and the limitations in terms of its execution – including economic constraints and problems of public order and armed groups; permits with Indigenous communities; difficulty of access to areas far from roads and highways; lack of technical forestry personnel to conduct surveys in certain sectors; changes in resource managers, responsible technical teams and weather conditions; the high diversity and variability of forests in the country – as well as the considerable logistical and economic efforts made by IDEAM and the SINA agencies that account for the complexity of the survey, it was decided that the first cycle should end in the year 2022. This will allow the NFI implementation to comply with the provisions of Decree 1655 of 2017 and, as a result, all efforts in the short term are focused on securing resources to complete the field surveys.

At the moment, agreements are underway with a number of IIAs, such as the John von Neumann Environmental Research Institute of the Pacific (Instituto de Investigaciones Ambientales del Pacífico – IIAP, according to its acronym in Spanish), which is expected to complete the Pacific region in 2021; the Amazonian Scientific Research Institute SINCHI (SINCHI Institute) to complete the clusters for the Amazon region; and the Alexander von Humboldt Biological Resources Research Institute (IAvH) to advance in the implementation of clusters in the Orinoco-Amazon foothills and the Caribbean region, and to complete the entire Orinoquía region by 2022.

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In addition, it is expected that additional resources will be leveraged through joint initiatives with the Ministry of the Environment and Sustainable Development to estimate blue carbon; this would leave only the clusters in the Andean region as pending. In this regard, IDEAM is making progress in defining a financial sustainability programme that guarantees resources for the completion of the baseline and the continuation of future NFI implementation cycles.

To strengthen data collection, IDEAM is developing the NFI information system, which is nested within the institutional information system; this will allow for the integration and interoperability with other forest monitoring systems such as the National Forest Information System, the Forest and Carbon Monitoring System, and the Greenhouse Gas Inventory Information System, thus advancing towards the consolidation of monitoring, reporting and verification tools in Colombia and improving the NFI reports.

Although no changes in the NFI design are currently being considered, discussions are underway to include new variables such as crown diameter and moisture in coarse woody debris.

Integration with remote sensing systems and interoperability with other systems is also foreseen in order to move towards the construction of the country's Forest Monitoring System, in line with the commitments made in the framework of the Paris Agreement.

At present, IDEAM is preparing all the necessary documentation (manuals, guides, protocols, among others) to support the certification process to be carried out in 2022, in compliance with the commitments under the SEN and the implementation of the technical standard NTC PE 1000 of 2017 (DANE, 2020).

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Chapter 12

COSTA RICA

NATIONAL FOREST INVENTORY OF COSTA RICA

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12.1 HISTORICAL OVERVIEW OF NATIONAL FOREST INVENTORIES IN COSTA RICA

In 2000, Costa Rica was selected as the pilot country to develop concrete experiences in establishing a nationwide forest inventory that combined biophysical and socioeconomic aspects of forest use. The Global Forest Resources Assessment (FRA) of the Food and Agriculture Organization of the United Nations (FAO) and the Tropical Agricultural Research and Higher Education Centre (CATIE) initiated this idea, with the aim of introducing new approaches and strengthening implementation capacity at the national level to improve global forest information (Kleinn *et al.*, 2006). The methodology and experiences developed in this pilot study were transferred to other tropical countries through the programme of support to National Forest Monitoring and Assessment (NFMA), which has assisted several countries to improve field data collection and the generation of forest information, including Brazil, Cameroon, Guatemala, Honduras, Kenya, Nicaragua, the Philippines and Zambia.

Later, in 2012, Costa Rica started the planning and implementation of the first National Forest Inventory (NFI) led by the National System of Conservation Areas (SINAC) with technical support from the German Corporation for International Cooperation (GIZ), through the Reducing Emissions from Deforestation and Forest Degradation in Central America and the Dominican Republic Programme (REDD/CCAD-GIZ Programme) (SINAC and REDD/CCAD-GIZ Programme, 2015a). The implementation of the first NFI was completed in 2015 and the following set of documents was published:

- Volume 1. Base map, for stratification into forest types (SINAC and REDD/CCAD-GIZ, 2015b);
- Volume 2. Field manual, for the establishment and measurement of sample plots (SINAC and REDD/CCAD-GIZ Programme, 2014a);
- Volume 3. Field protocol for tree species identification (SINAC and REDD/CCAD-GIZ Programme, 2014b);
- Volume 4. Conceptual and methodological framework for Phase I (pre-sampling) and Phase II (sampling) (SINAC and REDD/CCAD-GIZ Programme, 2015a);
- Final report on results and characterization of forest resources (SINAC and REDD/CCAD-GIZ Programme, 2015c).

The objective of the first NFI was to determine the stock, characteristics and state of the country's forest resources as a basis for guiding decision-making on forest land management and administration. At the same time, the baseline of carbon emissions was established for the implementation of measurement, reporting and verification (MRV) within the framework of the National REDD+ Strategy (MINAE, 2015). The information from the first NFI has been used by institutions for decision-making and serves as a basis for the management of the country's forest resources and the formulation of policies for the conservation, management and administration of natural resources.

The specific objectives of the first NFI are listed below:

- *determine the country's forest cover area by forest type;*
- *determine stock and productive state by forest type (dendrometry, species, abundance, biomass and related carbon stock);*
- *serve as a basis for determining rates of forest recovery, deforestation and degradation;*
- *produce information for the measurement, reporting and verification (MRV) system for the National REDD Strategy – Costa Rica;*
- *produce information to guide forest land management and meet the country's national and international commitments (SINAC and REDD-CCAD-GIZ Programme, 2014c, p. 3).*

The population of interest of the first NFI was the area of forest ecosystems in Costa Rica. The sampling design was pre-stratified with systematic distribution and a random starting point for the sampling points. This inventory considered the following six strata: mature forest, secondary forest, mangrove stand, palm forest, grassland with trees and forest plantation. Different sampling intensities were applied to the strata to achieve a pre-established error rate per stratum. Given that an up-to-date map of forest types did not exist at the time of developing the design, a regular hexagonal grid of 10 166 points (Figure 12.1) was used to classify the strata, using photointerpretation with satellite imagery of the highest resolution available.

The results generated from the NFI sought to provide detailed information related to the variables collected in the field plots and the relationships between the main dasometric, biodiversity and carbon dioxide (CO_2) pool variables (SINAC & REDD/CCAD-GIZ Programme, 2015c).

To implement the first NFI in SINAC, the Office of Natural Resources Management (Gerencia de Manejo de Recursos Naturales in Spanish), now known as the Department of Conservation and Sustainable Use of Biodiversity and Ecosystem Services (Departamento de Conservación y Uso Sostenible de la Biodiversidad y Servicios Ecosistémicos in Spanish), was designated as the coordinating agency. A Steering Committee was formed, composed of officials from SINAC and the National Forestry Financing Fund (FONAFIFO); its role was to guide activities in order to meet the established objectives and agreed MRV mechanisms for the National REDD+ Strategy.

The second NFI will be implemented between 2022 and 2025. Its methodology was adjusted based on the updated information needs within the framework of the National Land Use, Land Cover, and Ecosystems Monitoring System (SIMOCUTE); within this system, the NFI is the component for collecting field data on forests and trees outside forests and for meeting SINAC's information needs so that it can fulfil its responsibilities. This change will improve decision-making for strategic territorial planning and provide data for the MRV of the REDD+ Strategy, the nationally determined contributions (NDCs) of the agriculture, forest and other land use sectors, as well as for national and international reports such as FRA, the Convention on Biological Diversity (CBD) and the Ramsar Convention (Convention on Wetlands of International Importance).

Other improvements foreseen in the second NFI in Costa Rica are the implementation of a continuous monitoring system; the expansion of the population of interest to the entire national territory; and the application of systematic, post-stratified sampling, with systematic sample selection and a randomisation factor. Furthermore, another very important aspect is that the second NFI will be institutionalized within SINAC, which means that the field measurements will be carried out with staff from the conservation areas.

More specifically, the second NFI cycle will respond to the following information needs:

- land cover and land use change;
- ecosystem health and forest biodiversity;
- land degradation (emphasis on forests);
- forest yield and growth;
- forest regeneration on non-forest land;
- changes in carbon stock in forests and other wooded land.

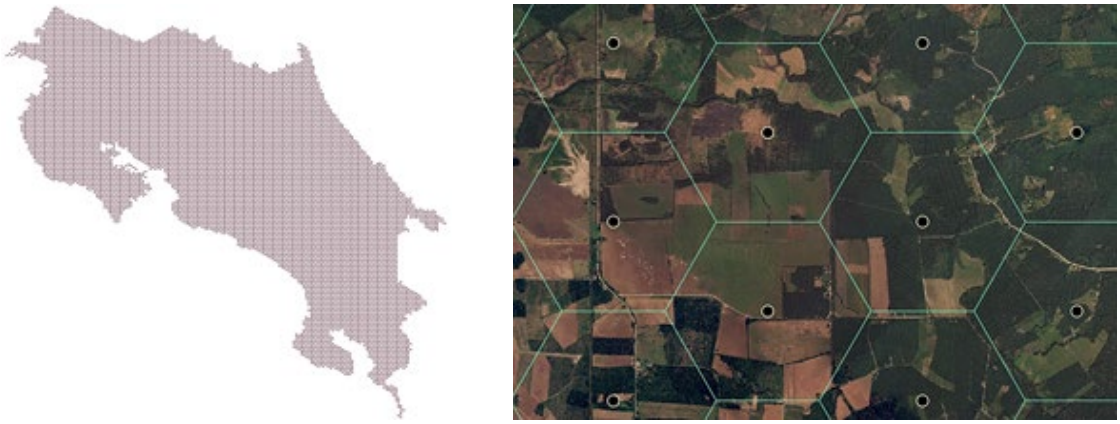
The transition to the new design will be carried out progressively, so that the information collected in the first inventory can be recovered and made compatible with the data platform developed for the previous NFI. Table 12.1 shows the characteristics of the two forest inventories in Costa Rica.

12.2 TERMS AND DEFINITIONS RELEVANT TO THE IMPLEMENTATION OF THE NATIONAL FOREST INVENTORY

The definition of forest for the first NFI was the same definition used for the Clean Development Mechanism projects and for the National REDD+ Strategy (Table 12.2), which was agreed to during workshops held in 2011 (MINAE, 2015). In addition, there is a definition of each type of forest measured: mature forest, secondary forest, palm forest, mangrove stand and forest plantations. In this NFI, no categories were defined related to other land with tree cover, which is reported in FRA and which, in the case of Costa Rica, corresponds to paramos (FAO, 2014). The first NFI also included the category of grassland with trees, due to its importance for forest management in the country

FIGURE 12.1

Hexagonal grid of the National Forest Inventory of Costa Rica



The boundaries shown and the names and designations used on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any countries, territories, cities, areas, authorities, or delimitation of their frontiers or boundaries. Dotted lines on maps represent approximate boundaries for which there may not yet be full agreement.

Source: **Fallas, J.** 2021. *Inventario Forestal Nacional Costa Rica: Diseño conceptual y metodológico.* San José, National System of Conservation Areas, Ministry of Environment and Energy.

TABLE 12.1

Historical overview of the National Forest Inventory in Costa Rica

Inventory cycle	Implementation period	Scale	Sampling design	Number of sampling units
NFI 1	2012–2015	National	Pre-stratified, systematic selection with random starting point; not proportional to the population	280
NFI 2	2022–2025	National	Double sampling for post-stratification, with selection that is proportional to the population	445

Source: Prepared by the authors.

(SINAC and REDD/CCAD-GIZ Programme, 2015b); according to the FRA 2020 definition (FAO, 2018), this class is included within the category "other land with tree cover" (Table 12.2).

Non-forest land has been classified for FRA reporting under the "other land" category and is inferred to be all land that is not forest, grassland with trees, or paramo.

TABLE 12.2

Summary of definitions used to implement the first National Forest Inventory (2012–2015)

Term	Definition	Variables and thresholds
Forest	International definition: Area of land with a minimum size of 1.0 ha and a canopy cover of more than 30%, with trees able to reach a minimum height of 5 metres at maturity *in situ*. Young natural stands, and all plantations that have not yet reached a canopy cover of 30%, or a height of 5 metres, are considered forests (MINAE, 2015).	Minimum land area: 1.0 ha Canopy cover: ≥ 30% Tree height: ≥ 5 m Minimum width: not defined Exceptions: not defined
	Legal definition: Native or autochthonous ecosystem, disturbed or undisturbed, regenerated through natural succession or other forestry techniques, occupying an area of two or more hectares, characterized by the presence of mature trees of different ages, species and size, with one or more canopies covering more than seventy percent (70%) of that land area and where there are more than sixty trees per hectare of fifteen or more centimetres in diameter measured at breast height (DBH) (Costa Rica, 1996).	Minimum area: 2 ha Canopy cover: 70% Minimum width: not defined Exceptions: not defined
Other wooded land	Paramos: Area of natural vegetation located at high altitudes, above 3 100 metres above sea level. Low altitude vegetation communities, in humid and cold areas. The dominant vegetation is dwarf bamboo of the *Chusquea* genus interspersed with woody plants of families such as Ericaceae, Hypericaceae, Rosaceae and Asteraceae. Not measured in the field (FAO, 2014).	Minimum area: not defined Canopy: not defined Dominant vegetation: dwarf bamboo of the *Chusquea* genus interspersed with woody plants of families such as Ericaceae, Hypericaceae, Rosaceae and Asteraceae Minimum width: not defined. Exceptions: not defined.
Other land	Grassland with trees: trees on land dedicated to livestock farming with remnants of the original forest that was felled to create the pasture, or trees in agroforestry systems (SINAC and REDD/CCAD-GIZ Programme, 2015b). Non-forest: Other agricultural, urban or other uses.	Minimum area: not defined Canopy cover: 15%–30% Tree height: not defined Minimum width: not defined Exceptions: not defined
Volume	Total volume (m^3): living trees, for trees with a DBH of 2 cm or more. Includes bark (SINAC and REDD/CCAD-GIZ Programme, 2015c).	Minimum diameter (DBH, 1.30 m): ≥ 2 cm Stump and bark included Minimum stem end diameter: not defined Total height: from the base to the top of the crown Commercial height: from the base to the first branch or fork Group of species: all species, as identified in the field and sample collection
Biomass	Above-ground biomass: dry biomass (kg) of living trees of 2 cm DBH or more (SINAC and REDD/CCAD-GIZ Programme, 2015c). Below-ground biomass: Not measured. Necromass: Dry biomass of dead litter and fallen cylindrical and semi-cylindrical dead wood from stems and branches with a minimum diameter of 10 cm and a minimum length of 1,5 m. Dead standing trees and stumps are not included.	Above-ground biomass Minimum diameter (DBH, 1,30 m): 2 cm Below-ground biomass: not included Necromass Stumps (minimum diameter): not included Dead standing tree: not included Minimum diameter of fallen dead wood: 2 cm Minimum diameter of sifted litter: not defined

Source: **Costa Rica (Republic of)**. *Forestry Law No. 7575*, 1996; **FAO.** 2014. *Evaluación de los recursos forestales mundiales 2015: Informe Nacional Costa Rica*. Rome, FAO.; **MINAE (Ministry of Environment and Energy)**. 2015. *Estrategia Nacional REDD+ de Costa Rica. San José*.; **SINAC & REDD/CCAD-GIZ Programme.** 2015b. *Cartografía base para el Inventario Forestal Nacional de Costa Rica 2013-2014*. Prepared by Ortiz, E. et al. as consultants for the National Forest Inventory of Costa Rica, implemented by SINAC within the framework of the REDD/CCAD-GIZ Programme. San José.; **SINAC & REDD/CCAD-GIZ Programme**. 2015c. *Inventario Nacional Forestal de Costa Rica 2014-2015. Resultados y Caracterización de los Recursos Forestales*. Prepared by Emanuelli, P., Milla, F., Duarte, E., Emanuelli, J., Jiménez, A. & Chavarría, M.I. Reducing Emissions from Deforestation and Forest Degradation in Central America and the Dominican Republic Programme (REDD/CCAD-GIZ) and National System of Conservation Areas (SINAC), Costa Rica. San José.

12.3 SAMPLING DESIGN

The sampling method selection criteria used were as follows:

- objectives and information needs;
- nature of the sampling frame;
- desired accuracy (sampling error);
- time, costs and operational conditions;
- parameters of the population to be estimated;
- population variability.

The population of interest for the first NFI consisted of all natural forests, forest plantations and grassland with trees spanning 1 hectare (ha) or more and located in the mainland territory of Costa Rica (51 100 square kilometres). A systematic pre-stratified sampling system, not proportional to the stratum size, was used. A sampling of all land cover and land use classes was used to define the strata. A grid of 10 166 points was used for this purpose, in which the six strata mentioned above were visually interpreted using RapidEye satellite images with a resolution of 5 metres (m) (SINAC and REDD/CCAD-GIZ Programme, 2015a).

The fieldwork was conducted in two phases: 107 plots were sampled in Phase I and 173 plots were measured in Phase II. The desired sampling errors and sample sizes were determined based on the information requirements and variances obtained in Phase I (SINAC and REDD/CCAD-GIZ Programme, 2015a).

For the second NFI, the population of interest has been expanded to the entire mainland territory and continental islands of Costa Rica. This change will enable the measurement of forest resources in all land uses, as well as the monitoring of their changes. In addition, the second NFI follows an approach of permanent, continuous measurement for more accurate comparisons of changes in resource management over time. In terms of sampling design, an adjustment has been made to the size of the strata in order to obtain a probability that is proportional to the sample. Double sampling will be used for post-stratification, which will consist of two stages:

- First phase (photointerpretation): land cover and land use assessment for each point of the 10 166-point grid adopted by SIMOCUTE (with an equidistance of 2 500 m); it also serves as a basis for monitoring via visual interpretation of high-resolution images, which corresponds to SIMOCUTE's point-based land cover and land use monitoring system.
- Second phase (field campaign): refers to the measurement of the field plots to be selected as a subsample of the photo-interpreted plots, maintaining the selection of sampling units (SUs) using systematic selection with a random starting point.

Based on data from the first NFI (2012–2015), the NFI sample size was increased to 445 plots distributed throughout Costa Rica (Table 12.3). With these changes, the sampling error (95 percent confidence level) is expected to be 8 percent for the basal area variables in the forest domain.

The transition from the initial NFI design to the new design will be made progressively. Figure 12.2 shows a diagram of the transition, where the green bars correspond to the first NFI design and the red bars to the new design. The first cycle corresponds to the first NFI carried out in 2013–2014. The second cycle corresponds to the second NFI, which will start in 2022 and in which two-thirds of the SUs were selected with the design of the first NFI and one-third correspond to the SUs selected with the new design. In the third cycle, one-third of the

TABLE 12.3

Characteristics of the sampling design

Inventory cycle	Total land area (1 000 ha)	Number of sampling units			Total number of sampling units
		Forest	Other wooded land	Other land	
First NFI	5 100	203	0	73	276
Second NFI	To be defined	246	36	163	445

Source: Prepared by the authors.

SUs will correspond to the selection of the first NFI and two-thirds of the SUs will be selected based on the new design. From the fourth cycle onwards, all SUs will correspond to the selection of the new design. This approach will avoid the loss of information from the first cycle, in that it will allow for information on changes to be integrated progressively with subsequent cycles and will help to maintain the statistical premise of equal probability of sample selection.

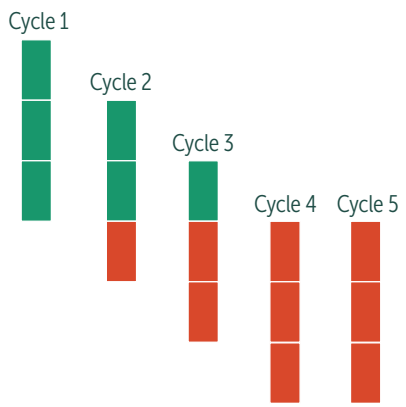
Table 12.4 summarises the sample distribution for each pre-stratum of the first NFI and the possible sample distribution by post-strata (based on the 2013 photointerpretation). The strata were grouped into three of the categories used by FRA, as follows:

- forests: these were grouped in the six classes used in the first NFI;
- other wooded land: refers to paramos;
- other land: includes all non-forest land (agriculture, livestock, urban) except grassland with trees which is included in the FRA subclass "other land (with tree cover)."

For the second NFI, an adjusted classification system will be used, which is designed to work collaboratively with SIMOCUTE (CENIGA, 2020).

FIGURE 12.2

Transition from the first National Forest Inventory design (2012–2015) to the new design



Note: The green bars correspond to the field survey conducted in 2013–2014 and the red bars to the new design to be implemented in 2022.

Source: **Scott, C.** 2017. *Recomendaciones detalladas para ajustar el diseño del inventario forestal nacional de Costa Rica en el marco del SIMOCUTE.* San José, National System of Conservation Areas, Ministry of Environment and Energy.

12.4 SAMPLING UNIT DESIGN

The sampling unit consists of a primary individual plot and several subplots of different dimensions depending on the variable to be measured (Figure 12.3), which are described below:

- primary plot (PP): 20 m × 50 m (1 000 m²) to measure trees with a diameter at breast height (DBH) greater than 10 centimetres (cm);
- secondary subplot (SS): 10 m × 20 m (200 m²) to measure trees between 2 cm and 10 cm DBH;
- tertiary subplot (TS): three plots with a radius of 1 m to measure regeneration of trees, shrubs and palms over 1.5 m in height and less than 2 cm DBH;
- quaternary subplot (QS): one 1 m² plot to measure herbaceous abundance;
- litter subplot (LS): use of a 50 cm² square at the four corners to collect and weigh litter on the ground;
- dead wood transept (DWt): line with a length of 20 m to estimate dead wood located equidistantly from the centre point of the PP;
- soil sample: to measure organic carbon in the soil.

12.5 LAND AREA, BIOMASS AND VOLUME CALCULATION

The detailed methods used to analyse each variable in the first NFI are explained in the report on the calculations and results of the Costa Rican NFI (SINAC and REDD/GIZ Programme, 2014b). Table 12.5 shows the equations used to calculate volume and biomass for each tree.

Thematic maps were also generated using geostatistics. The main objective was to estimate values at the national level through interpolation using data from field measurements for the 280 plots distributed in the six forest cover strata at the national level. The variables used in the interpolation were: diameter at a height of 1.30 m (DBH), height, basal area, CO_2 density in trees, branches, soil, lying dead wood and roots. The methodology used included the following steps (SINAC and REDD/GIZ Programme, 2015b):

TABLE 12.4

Characteristics of the sampling design of the first (pre-stratified) and second (post-stratified) National Forest Inventory

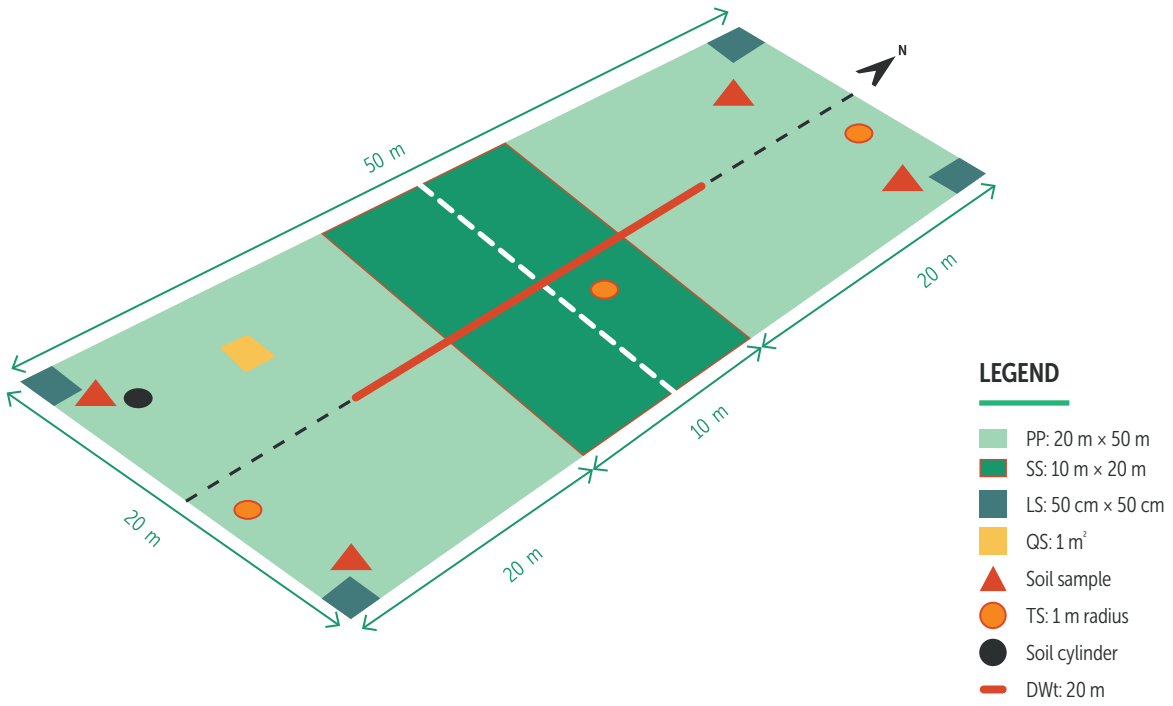
Global Forest Resources Assessment categories	Stratum	Land area (1 000 ha)	First pre-stratified NFI [1]	Second post-stratified NFI [2]
Forest	Broadleaved forest	2 438	167	246
	Mangrove forest	36	16	3
	Palm forest (yolillal)	n/a [3]	n/a	4
	Forest plantation	61	20	2
	Total	2 535	203	255
Other land (with tree cover)	Grassland with trees	638	71	n/a
	Total forest land	638	274	255
Other wooded land	Wetlands	n/a	n/a	21
	Paramo	15	n/a	2
Other land	Crops, grassland and bare soil	1 913	2	161
Inland water bodies	Inland water bodies	n/a	n/a	6
	Total	5 100	276	445

Notes: [1] The forest was mapped based on the photointerpretation used to plan the first National Forest Inventory (NFI), and the final data are presented in the results section (12.6). [2] Based on photointerpretation used to plan the second NFI. The tree cover in grasslands was not interpreted, as this process will be carried out during the development of the new forest map using automated algorithms. [3] n/a = not applicable.

Source: Prepared by the authors.

FIGURE 12.3

Plot design used for data collection for the Costa Rican National Forest Inventory



Notes: DWt: dead wood transept; LS: litter subplot; PP: primary plot; QS: quaternary subplot; SS: secondary subplot; TS: tertiary subplot.

Source: **SINAC & REDD/CCAD-GIZ Programme**. 2014a. *Manual de campo para el inventario forestal nacional de Costa Rica: Diseño de parcela y medición de variables de sitio y dasométricas*. Prepared by Jorge Fallas – consultant for the Reducing Emissions from Deforestation and Forest Degradation in Central America and the Dominican Republic Programme (REDD/CCAD-GIZ). San José.

TABLE 12.5

Equations used in volume and biomass calculations for the first National Forest Inventory

Variable	Equation	Reference
Total volume (m^3)	Trees ≥ 2 cm diameter at breast height (DBH) $V = BA \times Ht \times 0.5$ Where: *BA*: basal area *Ht*: total height (up to the highest part of the crown)	Linares (2015)
Biomass (kg)	**Above-ground biomass:** trees ≥ 2 cm DBH	Chave *et al.* (2005)
	$B = EXP\ (2.977) + ln\ (SG \times DBH^2 \times Ht)$ Where: *B*: biomass *DBH*: diameter at breast height *Ht*: total height *SG*: specific gravity	Specific gravity equation taken from Chave *et al.* (2006)
	$B = EXP\ (-1.80246 + 2.28927 \times ln\ (DBH))$	Fonseca, Federico and Rey (2009)
	For *Tectona grandis* $B = 10\ (-0.815 + (2.382 \times LOG_{10}\ (DBH)))$	Pérez and Kanninen (2003)

Source: **Chave, J., Andalo, C., Brown, S., Cairns, M.A., Chambers, J.Q., Eamus, D., Fölster, H.**, *et al.* 2005. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia*, 145: 87–99.; **Chave, J.** 2006. *Medición de densidad de madera en árboles tropicales: Manual de campo.* Proyecto Pan Amazonía, Red Amazónica de Inventarios Forestales.; **Fonseca, W.G., Federico, A.G. & Rey, J.M.** 2009. Modelos para estimar la biomasa de especies nativas en plantaciones y bosques secundarios en la zona Caribe de Costa Rica. *Bosque*, 30(1): 36–47.; **Linares, R.** 2015. *Guía para el desarrollo de la ordenación forestal integral y sostenible en Colombia.* Bogota, Ministry of the Environment and Sustainable Development.; **Pérez, L.D. & Kanninen, M.** 2003. Above-ground biomass of Tectona grandis plantations in Costa Rica. *Journal of Tropical Forest Science*, 15(1): 199–213.

- Exploratory data analysis: a descriptive statistics analysis was carried out to identify whether the distribution of the data was normal by means of the number of classes, distribution ranges, mode, median, variance, standard deviation, illustrating them with graphs, maps and perspective views, among others, in order to understand the information available for the 280 plots and each of the variables measured.
- Spatial correlation analysis: this analysis was used to identify the spatial dependence of the data. The semivariogram/surface covariance functions were used. The calculation of the semivariogram is one of the most important geostatistical tools in determining the characteristics of variability and correlation between the variables to be interpolated; this analysis provides information on how the variable changes from one location to another. The semivariogram was calculated in different directions (360°), which allowed the selection of a spherical model to model and interpolate the data.
- Application of interpolation tool using the inverse distance weighting (IDW) technique: there are different ways to derive a prediction for each location; each method is called a model. With each model, different assumptions are made about the data and some models are more applicable for certain data. The interpolation tool, used to generate the prediction surfaces using the 280 NFI plots as the base data, consisted of applying the IDW method using the Spatial Analyst extension of ArcGis Desktop.

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TABLE 12.6

Results of the first National Forest Inventory (2012–2015)

Variables	Result	Description
Land area of native forest (including primary, secondary, mangrove, palm and plantation forest) (1 000 ha)	2 648 51.9%	Land area ≥ 1 ha Country percentage
Land area of grassland with trees (1 000 ha)	1 219 31.5%	Land area ≥ 1 ha Country percentage
Forest land area (1 000 ha)	3 867 75.8%	Land area ≥ 1 ha Country percentage
Total volume of forest land (m^3/ha)	188.9 (± 21.5)	Trees ≥ 2 cm diameter at breast height (DBH) (confidence limits)
Total biomass of forest land (includes above-ground biomass, below-ground biomass, necromass) (t/ha)	156.5 (± 15.9)	Trees ≥ 2 cm DBH (confidence limits)

Source: Adapted from **SINAC & REDD/CCAD-GIZ Programme.** 2015c. *Inventario Nacional Forestal de Costa Rica 2014-2015. Resultados y Caracterización de los Recursos Forestales.* Prepared by Emanuelli, P., Milla, F., Duarte, E., Emanuelli, J., Jiménez, A. & Chavarría, M.I. Reducing Emissions from Deforestation and Forest Degradation in Central America and the Dominican Republic Programme (REDD/CCAD-GIZ) and National System of Conservation Areas (SINAC), Costa Rica. San José.

12.6 RESULTS OF THE FIRST CYCLE: LAND AREA, BIOMASS AND VOLUME

The results of the first NFI are summarised in Table 12.6 (SINAC and REDD/GIZ Programme, 2015c). The country's forest area was estimated at 2 572 873 ha, equivalent to 50.5 percent of Costa Rica's total land area. The forest area is divided into 30.3 percent mature forest, 18.5 percent secondary forest, 0.7 percent mangrove forest and 0.9 percent palm forest. In addition, there are 74 597 ha of forest plantations (1.5 percent) and 1 219 425 ha of grassland with trees (31.5 percent), making a total of 3 866 895 ha of forest land, equivalent to 75.5 percent of the country. The map was limited by clouds on 481 997 ha (9.4 percent). The overall accuracy of the map for land area calculation was 89 percent, joining the categories classified as forest and grassland with trees.

The average total volume of all forest land was estimated at 188.9 cubic metres per hectare and the biomass at 156.5 tonnes per hectare.

Figure 12.4 shows the map of forest type distribution in Costa Rica.

12.7 IMPLEMENTATION AND QUALITY CONTROL

Several quality control and quality assessment activities were carried out in the first Costa Rican NFI.

For the field survey, the country was divided into five operational regions: North Pacific and Central Valley, Central and South Pacific, North Zone and North Caribbean, Central and South Caribbean, and sites of difficult access (Cordillera de Talamanca). The work was outsourced, for which terms of reference were formulated and a selection process was carried out. A crew led by a forestry manager with experience in conducting forest inventories and knowledge of the sites to be sampled worked in each region. A description of the roles and responsibilities of each of the field crew members was prepared. All crews were trained prior to the start of the fieldwork, based on the field manual and protocol for the identification, collection, transport and processing of botanical samples. During the fieldwork, crew leaders were contacted by telephone and e-mail to resolve any queries during the inventory exercise. A field visit was made to four of the five crews.

The field data was collected by completing forms which were then entered into Excel spreadsheets and scanned. In addition, the activities carried

out by the crews were documented in a report. A photographic field file was created for each of the plots. Routine checks were performed to assess the consistency, integrity and completeness of the dasometric, dendrological, edaphic and positioning data for each plot.

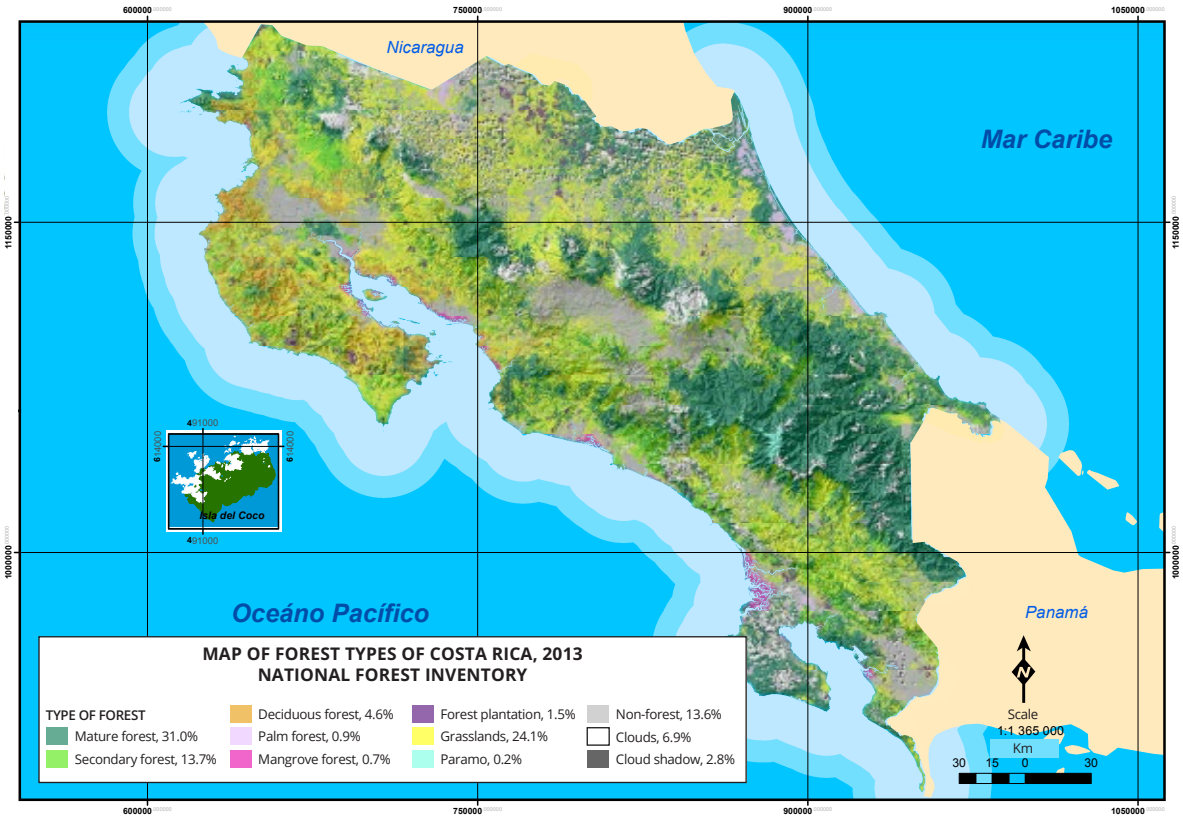
High-resolution images (Google) and orthophotos at a scale of 1:5 000 – dating from 2005 and available in the National Territorial Information System (Sistema Nacional de Información Territorial) – were used to verify the strata. Once the data were received from the crew officer, they were reviewed by the field director and the dendrology coordinator; if errors, omissions or inconsistencies were detected, the information was returned to the crew officer with the relevant observations to rectify or record the discrepancy.

An independent verification of 33 plots was carried out by an independent field crew.

The information obtained from Phase I was submitted by each crew through a standardized Excel template that had been approved by the SINAC professional team; these spreadsheets were reviewed prior to delivering the information to the REDD/CCAD-GIZ Programme for processing. The task of analysing the information was entrusted to Sud-Austral Consulting SpA, whose staff compared the information in the Excel spreadsheet with the original field forms that had been scanned. After verifying inconsistencies in the information and any concerns following the review by SINAC's professional counterpart, the final database was accepted in order to streamline data processing.

FIGURE 12.4

Map of forest type distribution in Costa Rica



The boundaries shown and the names and designations used on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any countries, territories, cities, areas, authorities, or delimitation of their frontiers or boundaries. Dotted lines on maps represent approximate boundaries for which there may not yet be full agreement.

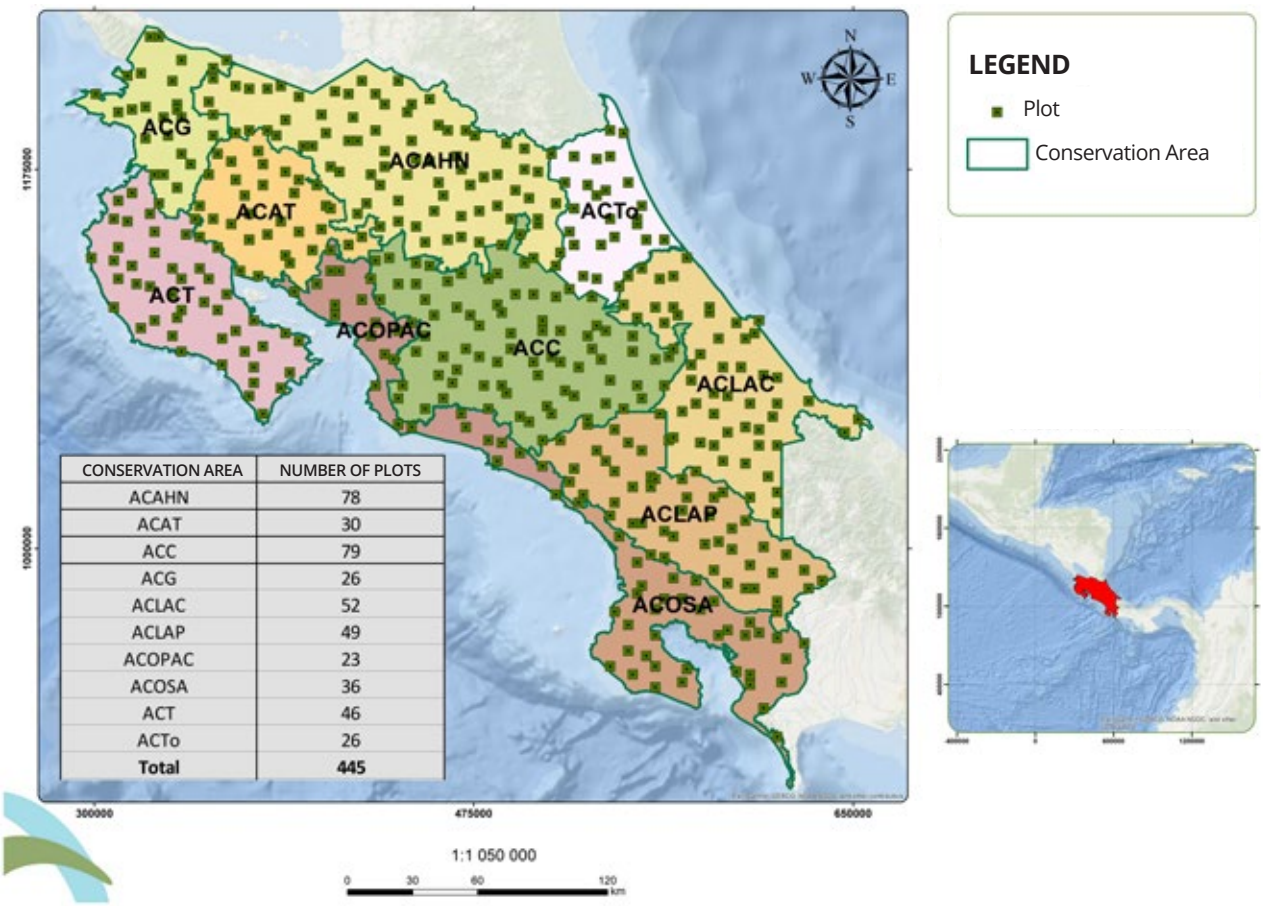
Source: **SINAC & REDD/CCAD-GIZ Programme.** 2015b. *Cartografía base para el Inventario Forestal Nacional de Costa Rica 2013-2014.* Prepared by Ortiz, E. et al. as consultants for the National Forest Inventory of Costa Rica, implemented by SINAC within the framework of the REDD/CCAD-GIZ Programme. San José.

The National System of Conservation Areas decided to implement the second NFI as an institutional project with its own resources (human, financial and capital); to achieve this, the sample was distributed temporally in order to measure 20 percent of the plots each year. Considering a four-year cycle (2022–2025), it is estimated that an average of 111 plots will be measured per year (Figure 12.5).

For the operations of the second NFI, SINAC has designed a management plan to organize the available resources required for this new institutional project throughout its life cycle (initiation and formalization, preparation, implementation, monitoring and closure). An NFI team has been officially appointed to work on these activities.

FIGURE 12.5

Location of plots of the second National Forest Inventory and their distribution per Conservation Area



CONSERVATION AREA	NUMBER OF PLOTS
ACAHN	78
ACAT	30
ACC	79
ACG	26
ACLAC	52
ACLAP	49
ACOPAC	23
ACOSA	36
ACT	46
ACTo	26
Total	**445**

The boundaries shown and the names and designations used on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any countries, territories, cities, areas, authorities, or delimitation of their frontiers or boundaries. Dotted lines on maps represent approximate boundaries for which there may not yet be full agreement.

Note: Conservation Areas correspond to the territorial units into which the National System of Conservation Areas is divided.
Source: **SINAC (National System of Conservation Areas).** 2021. *Mapa de ubicación de parcelas del IFN-CR por áreas de conservación* (unpublished). San José.

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12.8 OTHER VARIABLES COLLECTED IN THE COSTA RICAN NATIONAL FOREST INVENTORY

The first NFI collected data not only from forests, but also from grasslands with trees, with the objective of monitoring forest resources on land dedicated to livestock farming that still had remnants of natural forests or that could be improved to create silvopastoral systems.

In the second NFI, data will be collected from plots located throughout the national territory and from all land uses, in order to expand the monitoring of trees to include not only those in forests, but also outside of forests. This will facilitate a more comprehensive calculation of biomass and carbon. To this end, a classification of land use and land cover has been developed, in which land cover has been defined as "the biophysical cover present on a site with its natural and anthropic elements" and land use as "functional use of a site such as biophysical and cultural elements, such that its determination requires a human perspective and the interpretation of the activities carried out on the land cover of a given site," according to the SIMOCUTE Technical Board for the classification of land use and land cover (CENIGA, 2020).

12.9 FUTURE PROSPECTS

The integrated monitoring of natural resources is one of the objectives of SIMOCUTE and the NFI has been one of the pillars of this process. The hexagonal grid is the basis for monitoring changes in land use and land cover through the visual interpretation of points, a methodology that has been used to update the reference level for REDD+ and the Greenhouse Gas Inventory. This information will also be used to generate post-strata to improve the NFI estimates.

In addition, the selection of samples across all land uses will facilitate the inclusion of other variables not only from the environmental sector, but also from the agricultural sector. Discussions on the inclusion of biodiversity variables (flora and fauna), as well as biophysical variables in agriculture and livestock, are currently underway.

In the same vein, it is important to mention that the implementation of the NFI is within the legal authority of SINAC, according to Article 6, paragraph h of the Forestry Law No. 7575 (Costa Rica, 1996); thus, it has been decided to carry out this project with SINAC's own resources for the first time, in order to gain experience, gather lessons learned and be able to continue forest monitoring over time, based on a philosophy of continuous improvement.

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NEXT CHAPTER

ECUADOR

Chapter 13

ECUADOR

NATIONAL FOREST INVENTORY OF ECUADOR

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13.1 HISTORICAL OVERVIEW OF NATIONAL FOREST INVENTORIES IN ECUADOR

Ecuador currently has a national forest inventory; however, a number of pioneering initiatives have been implemented since 1963. Among these is the inventory carried out in the province of Esmeraldas covering the humid forests of Chocó, which was supported by the United Nations Development Programme (United Nations Special Fund). The information collected was used for the development of forest industries, adopting an extractive approach from a commercial forestry exploitation perspective (Aguirre *et al.*, 2010).

The next inventory was carried out in 1975 in the southern part of Ecuador, in the provinces of El Oro, Loja, Zamora Chinchipe and Morona Santiago, which contain humid and dry forests. This initiative was carried out with the support of SCET International of France and Agrofor of Ecuador (Agrofor, Predesur and SCET International, 1978).

To complement the 1975 inventory, the Center for Integrated Surveys of Natural Resources by Remote Sensing (CLIRSEN) and the National Forestry Directorate (Dirección Nacional Forestal – DNF, according to its acronym in Spanish), now known as the Forestry Directorate of the Ministry of the Environment, Water and Ecological Transition (MAATE), assessed the forests in the central Ecuadorian Amazon with the support of remote sensing techniques such as the interpretation of Landsat and radar images, and the analysis of aerial photographs (CLIRSEN and DINAF, 1985).

Previous experiences of forest inventories demonstrate the efforts that have been made to know the state of the country's forest resources, yet these initiatives were undertaken at subnational level with specific objectives and without standardized methodologies.

For this reason, in 2006 the DNF launched a national-level forest resources assessment in three areas: forest inventory, socioeconomic analysis and carbon density modelling (Aguirre *et al.*, 2010), which became the national forest assessment (NFA[1]). This project was conceptualised 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 the requirements for accessing international carbon markets; iii) offer a periodicity for long-term monitoring; and iv) provide flexibility and adaptability for future information needs (Aguirre *et al.*, 2010) as part of Ecuador's

[1] For the purposes of this publication, in the case of Ecuador the NFA refers to the National Forest Inventory (NFI).

forest governance related to the "generation of forest information" (MAE, 2013a). The measurement phase was implemented in 2009 with technical support from the Food and Agriculture Organization of the United Nations (FAO) through the Sustainable Forest Management in a Changing Climate project, and financial support from the Government of Finland (Aguirre *et al.*, 2010), using the methodological framework developed in previous years (Table 13.1).

In 2018, Ecuador began its second NFA under the legal framework of the Organic Code on the Environment, published in 2017 in the Official Gazette Supplement No. 983, which grants the National Environmental Authority the power to carry out and update the National Forest Inventory (NFI). The NFI is defined in the Regulations of the Organic Code on the Environment, in the Official Register Supplement No. 507 of 2019, as the following:

> *a methodological process that provides information periodically through field observations and measurements, supplemented by geographic analysis processes on the stock, characteristics and state of the country's forest resources, as the basis for guiding forest land management regarding decision-making and administration, as well as the formulation of public policies (Regulations of the Organic Code on the Environment, 2019, art. 347).*

Article 348 of the Regulations of the Organic Code on the Environment describes the objectives of the NFI, which range from the design of the process to the generation of forest management indicators.

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13.2 TERMS AND DEFINITIONS RELEVANT TO THE IMPLEMENTATION OF THE LAST NATIONAL FOREST INVENTORY

The terms and definitions used for the design and reporting of information derived from the NFA are consistent with national regulations, the Global Forest Resources Assessment (FRA) report and the Intergovernmental Panel on Climate Change (IPCC) good practice guidance for including NFI data in the United Nations Framework Convention on Climate Change (UNFCCC) reports.

The Regulations of the Organic Code on the Environment recognise forests as part of the National Forest Heritage, including those that become part of the heritage through ecological restoration mechanisms. Article 89 of the Organic Code on the Environment states that the National Forest Heritage is made up of natural forests and land that is suitable for forests. It includes areas under the direct jurisdiction of the State or in the public domain; non-tree vegetation whether or not it is associated with the forest; disturbed and secondary forests; and land under ecological restoration or protection.

Ministerial Agreement 116, which issues the REDD+ Forests for Good Living Action Plan and establishes the guidelines for the implementation of the REDD+ mechanism (Reducing Emissions from Deforestation and Forest Degradation) in Ecuador, defines a forest as:

> *A natural or cultivated vegetation community of at least one hectare, with trees at least five metres high and at least thirty percent canopy cover. Forests can be divided into native forests and forest plantations. Areas covered with bamboo and native palms are included, as long as they reach the established minimum limit in terms of minimum area, height and canopy. Tree formations used in agricultural production systems, such as fruit tree plantations, African palm plantations and agroforestry systems, are excluded. Trees growing in urban parks and gardens are also excluded (MAE, 2016, p. 189).*

In relation to the terms and definitions of FRA 2020 (FAO, 2018), the land covered with forest is categorised into i) native forest, which corresponds to "forest"; ii) plantation, which is considered "other wooded land"; and iii) non-forest land is included in the "other land" category (Table 13.2).

TABLE 13.1

Historical overview of national forest inventories in Ecuador

Inventory cycle	Implementation period	Scale	Sampling design	Number of sampling units
NFA 1	2009–2013	National	Stratified systematic double sampling with random starting point	630
NFA 2	2018–2023	National	Stratified systematic sampling	1 744 [1]

Note: [1] Sampling units that correspond to forest cover only.
Source: Prepared by the authors.

TABLE 13.2

Summary of definitions used to implement the first national forest assessment

Term	Definition	Variables and thresholds
Forest	Includes all land with forest vegetation and systems with the potential to reach established thresholds for identifying a forest and consistent with the thresholds used to define forest land in the greenhouse gas inventory (MAE and UN-REDD Programme, 2010)	Minimum canopy cover: 30% Canopy height: from 5 m Minimum mapping area: 1 ha
Other wooded land	Traditional forest plantations for production and restoration purposes (MAE and FAO, 2014a)	Minimum canopy cover: 30% Canopy height: from 5 m Minimum mapping area: 1 ha
Other land	Includes bare soil, rock, ice and all areas not included in the following categories: – crop areas with cultivated land and agrosilvopastoral systems – pasture areas with grazing land, including non-tree vegetation systems – water bodies, including areas of peat extraction and land covered or saturated with water – infrastructure, including transport infrastructure and human settlements (MAE and UN-REDD Programme, 2010; MAE and FAO, 2014a)	Canopy cover: < 30% or non-existent Canopy height: not applicable Minimum mapping area: 1 ha
Volume	Commercial timber volume with bark, excluding branches, using forestry regulation formula	Living trees: 10 cm diameter at breast height (DBH) Bark: included Branches: excluded
Biomass	Above-ground and below-ground biomass estimated from allometric equations of Chave *et al.* (2005) with easily measured dasometric variables (MAE and FAO, 2014a)	Living trees ≥ 10 cm DBH: Specific density based on Zanne *et al.* (2009) table, estimated for family, genus or species; in unidentified species a weighted average is used For palms with DBH ≥ 10 cm, specific density is not used; biomass is estimated from allometric equations Standing dead trees with and without branches: Weighted average of specific density (0.53 g/cm^3) Discount: 50% dead trees without branches and 25% dead trees with branches (Brown *et al.*, 1995 and Saldarriaga *et al.*, 1998, cited by Sarmiento, Pinillos and Garay, 2005) Stumps: Diameter and height, with form factor of 1, assuming a complete cylinder

Source: Prepared by the authors.

Ecuador's native forests are divided into 65 ecosystems according to their hydrological, geomorphological, bioclimatic and biological characteristics. For the national forest assessment, these are grouped into nine forest strata based on the main physiognomic, geomorphological and floristic characteristics of the ecosystems (Table 13.3).

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The second NFA measurement cycle maintains the land use classification and native forest strata categorisation of the first inventory.

TABLE 13.3

Forest strata of the national forest assessment which correspond to the forest category of the Global Forest Resources Assessment 2020

No.	Stratum	Definition
1	**Pluviseasonal Dry Forest (BSP)**	Rainfall less than 1 600 mm with five to six dry months Altitudinal range from 800 metres above sea level (masl) to 2 600 masl Canopy height 5 m or higher Xerophytic floristic composition (Aguirre, Linares-Palomino and Kvist, 2006)
2	**Andean Dry Forest (BSA)**	Temperature between 6 °C and 17 °C Annual rainfall less than 1 600 mm Altitudinal range between 0 masl and 700 masl (MAE, 2013b; MAE and FAO, 2014a) Canopy between 5 m and 10 m in height There are areas where the vegetation is shrubby, thorny, xerophytic, not very dense and up to 4 m high, due to anthropogenic influence. However, the diversity of tree species is low (Aguirre, Kvist and Sánchez, 2006)
3	**Andean Foothills Evergreen Forest (BSVAPM)**	Temperature between 6 °C and 17 °C Annual precipitation of more than 3 406 mm Altitudinal range between 300 masl and 1 500 masl (MAE, 2013b; MAE and FAO, 2014a) Canopy reaches 30 m in height, fairly dense undergrowth and abundant presence of epiphytes in the lower stratum (Sierra, 1999; Baquero *et al.*, 2004)
4	**Andean Montane Evergreen Forest (BSVAM)**	Annual temperature between 15 °C and 24 °C Annual precipitation of 2 449 mm Altitudinal range between 1 300 masl and 1 800 masl Canopy between 25 m and 30 m in height (MAE, 2013b; MAE and FAO, 2014a)
5	**Andean Evergreen Forest of Ceja Andina (BSVCA)**	Temperature between 6 °C and 17 °C Annual precipitation of 922 mm (Baquero *et al.*, 2004) Altitudinal range between 1 500 masl and 4 000 masl Tree canopy between 5 m and 10 m high (MAE, 2013b; MAE and FAO, 2014a)
6	**Amazon Lowlands Evergreen Forest (BSVTBM)**	Temperatures between 16 °C and 26 °C Precipitation of more than 2 000 mm Typically, more than 200 species greater than 10 cm DBH in one hectare (Sierra, 1999; MAE, 2001) Canopy of 30 m to over 40 m in height Abundant epiphytes, lianas and climbers, and a fairly dense herbaceous stratum (MAE, 2013b; MAE and FAO, 2014a)
7	**Chocó Lowlands Evergreen Forest (BSTBCH)**	Temperatures between 16 °C and 26 °C Average annual precipitation of 2 000 mm Canopy is established at 30 m Studies indicate that in one hectare of this forest type, more than 100 tree species with a DBH greater than 10 cm can be found (Sierra, 1999; MAE, 2001; Boada, 2006)
8	**Mangrove (M)**	Canopy is variable and generally between 3 m and 12 m in height, although on the northern coast of Ecuador it can reach 25 m or more (Sierra, 1999; Bodero, 2005) Amphibian association of trees or shrubs, evergreens
9	**Moretales (Mo)**	Temperatures between 16 °C to 26 °C Precipitation of more than 2 000 mm Vegetation adapted to flood zones Canopy consisting mainly of *Mauritia flexuosa* canopies of more than 20 m in height

Source: **Aguirre, Z., Linares-Palomino, R. & Kvist, L.P.** 2006. Especies leñosas y formaciones vegetales en los bosques estacionalmente secos de Ecuador y Perú. *Arnaldoa*, 13(2): 324–350.; **Aguirre, Z., Kvist, L.P. & Sánchez, O.T.** 2006. Bosques secos en Ecuador y su diversidad. In: M. Moraes R., B. Øllgaard, L.P. Kvist, F. Borchsenius & H. Balslev, eds. *Botánica Económica de los Andes Centrales*, pp. 162–187. La Paz, Universidad Mayor de San Andrés.; **Baquero, F., Sierra, R., Ordóñez, L., Tipán, M., Espinosa, L., Rivera M.B. & Soria, P.** 2004. *La vegetación de los Andes del Ecuador: Memoria explicativa de los mapas de vegetación potencial y remanente de los Andes del Ecuador a escala 1:250.000 y del modelamiento predictivo con especies indicadoras.* Quito, EcoCiencia, CESLA, Corporación EcoPar, MAG SIGAGRO, CDC – Jatun Sacha, División Geográfica – IGM.; **Boada, C.** 2006. El Chocó biogeográfico. In: *Ecuador Terra Incognita*. Cited 8 November 2021.; **Bodero, A.** 2005. *El bosque de manglar de Ecuador.* Quito, Grupo Majagual; **MAE (Ministry of Environment of Ecuador).** 2001. *La biodiversidad del Ecuador: Informe 2000.* Quito, MAE, EcoCiencia & International Union for Conservation of Nature.; **MAE.** 2013b. *Sistema de clasificación de los ecosistemas del Ecuador continental.* Quito.; **MAE & FAO.** 2014a. *Resultados de la Evaluación Nacional Forestal.* Quito.; **Sierra, R.**, ed. 1999. *Propuesta preliminar de un sistema de clasificación de vegetación para el Ecuador continental.* Quito, Proyecto INEFAN/GEF-BIRF & EcoCiencia.

13.3 SAMPLING DESIGN

The first NFA had a multipurpose approach and its main variables are maintained in the second cycle (Table 13.4). The variables used for the forest inventory design are timber volume and biomass contained in the strata where a 10 percent error was established. Other variables of analysis are grouped by theme.

Given that the entire population of trees cannot be measured directly in practice, individual samples are taken to characterize the population. The sampling design considers vegetation categories in order to control the variance of the estimates of interest (Casanoves, Cifuentes and Chacón, 2017).

In the first NFA, a 1 kilometre (km) by 1 km grid was used to estimate the sample for a proportional distribution in relation to each stratum, based on a pilot with double sampling for stratification. Due to geographical and economic factors, a random start was planned for the implementation of the inventory (see Table 13.5 and Figure 13.1), under the premise that each sampling unit would have the same probability of being selected.

The sampling unit established is an L-shaped cluster consisting of three plots measuring 60 metres (m) by 60 m and separated by a distance of 250 m. Each plot contains sampling subunits for the variables to be assessed (Table 13.6).

The conceptual framework governing the design of the second NFA was built on the basis of the updated information requirements at the institutional level to strengthen forest management and the results of the first NFA; changes in the way some variables are measured can be compared in Table 13.6.
The second NFA cycle has the same population approach, with forest and non-forest areas, and the subpopulation corresponds to areas with bioclimatic and geomorphological boundaries that have forests with distinctive floristic structures and compositions, referred to as strata (Table 13.3). The geographic information is generated by the National Forest Monitoring System technical team at a scale of 1:100 000; it consists of the different types of forest cover and the assignment of the stratum attribute to the clusters. The design features stratified systematic sampling, which distributes the sampling units in a regular 10 km by 10 km pattern throughout the country (Figure 13.2), except for the Galapagos Islands and small islands within the national territory. The fixed grid maximises the average distance between the sampling units, with the aim to minimise the spatial correlation among the observation points (Czaplewski, McRoberts and Tomppo, 2004).

Regarding the sample distribution, an allocation that is proportional to the area of each stratum is considered to ensure that the error is within the established threshold of 5 percent. The calculation considers forest and non-forest areas.

TABLE 13.4

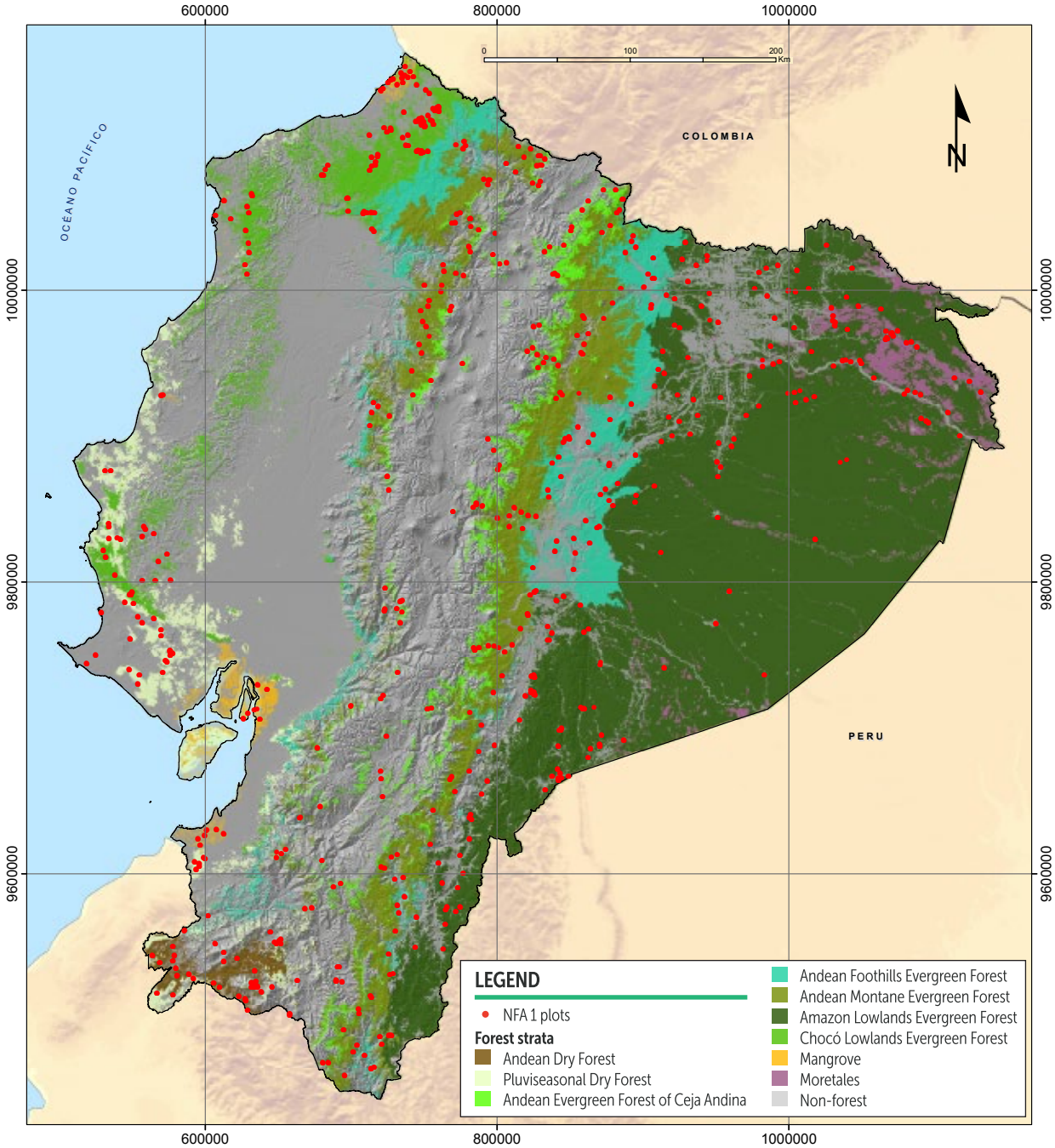
Main variables to be assessed in the second National Forest Inventory

Theme	Variable	Unit
Productivity of natural forests	Number of living trees	Number of living trees per hectare
	Commercial volume of standing trees	Cubic metres per hectare per year
	Potential volume for forest harvesting	Cubic metres per hectare per year
	Total growing stock volume	Cubic metres per year
State of the forest	Accessibility for forest management	Kilometres to roads
	Area change – Map	Hectares
	Area of forest and other vegetative cover – Map	Hectares
Forest biodiversity	Richness	Number of species
Carbon content in biomass	Above-ground carbon	Tonnes of carbon per hectare
	Below-ground carbon	
	Soil organic carbon	
	Carbon in leaf litter	
	Dead wood carbon	

Source: Prepared by the authors.

FIGURE 13.1

Map of forest strata from the first national forest assessment and sampling units based on random start



The boundaries shown and the names and designations used on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any countries, territories, cities, areas, authorities, or delimitation of their frontiers or boundaries. Dotted lines on maps represent approximate boundaries for which there may not yet be full agreement.

Source: **MAE & FAO.** 2014a. *Resultados de la Evaluación Nacional Forestal.* Quito.

However, only clusters with forest cover are measured in the field; non-forest units are surveyed with the support of geographic information systems. Given that the spatial pattern of the clusters varies between the first and second inventory, the loss of information should be avoided. For this reason, a gradual transition is proposed towards the established systematic approach, which allows for intensifying or reducing the number of sampling units in areas of interest.

The transition consists of resampling a percentage of clusters from the first assessment and incorporating new clusters in two measurement cycles.

TABLE 13.5

Distribution of sampling units per forest stratum

Name of the stratum	Total land area (1 000 ha)	Number of sampling units			Total number of sampling units
		Forest	Other wooded land	Other land	
Andean Dry Forest	162.96	41	n/a	n/a	41
Pluviseasonal Dry Forest	399.32	54	n/a	n/a	54
Andean Montane Evergreen Forest	1 888.67	154	n/a	n/a	154
Andean Evergreen Forest of Ceja Andina	502.77	60	n/a	n/a	60
Andean Foothills Evergreen Forest	1 079.7	84	n/a	n/a	84
Amazon Lowlands Evergreen Forest	6 293.51	174	n/a	n/a	174
Chocó Lowlands Evergreen Forest	465.71	87	n/a	n/a	87
Mangrove	104.57	30	n/a	n/a	30
Moretales	466.07	27	n/a	n/a	27
Total	**11 363.28**	**711**	**n/a**	**n/a**	**711**

Notes: The sampling design of the first national forest assessment (NFA 1) considered an initial map to estimate samples based on land area per forest type, which was developed with data from a map made by Dr Rodrigo Sierra in 1999, as it was the only national-scale information available until 2009. However, NFA 1 results were based on forest cover data from official maps of the Ministry of Environment of Ecuador (MAE) generated between 2010 and 2014, which have assumptions that differ from those of the 1999 map. The data reported to the Global Forest Resources Assessment (FRA) comes from the official maps of Ecuador. n/a: not applicable.

Source: **MAE & FAO.** 2014a. *Resultados de la Evaluación Nacional Forestal.* Quito.

13.4 SAMPLING UNIT DESIGN

The clusters are composed of three plots arranged in an L-shape and spaced 250 m apart from each other.

The plots have sampling subunits (Figure 13.3) that are designed to collect information on living trees, dead standing trees and stumps, lying or dead wood, leaf litter, soil organic carbon, regeneration and biomass of *Chusquea* and *Guadua* bamboo formations. A summary of the sampling subunit characteristics is shown in Table 13.6.

13.5 FOREST LAND AREA, VOLUME AND BIOMASS CALCULATION

Forest area

The forest cover of the first NFA was stratified with information available up to 2012, including vegetation formations from Sierra (1999), historical deforestation maps produced by MAATE for 1990, 2000 and 2008, and preliminary information from the vegetation map of Ecuador at a scale of 1:100 000 (MAE, 2013a).

The work consisted of differentiating homogeneous areas in terms of biomass according to their climatic and physiognomic characteristics (MAE and UN REDD Programme, 2010); the adjustment was carried out using photointerpretation techniques on 12 million hectares of remnant forest (MAE and UN-REDD Programme, 2010).

Volume

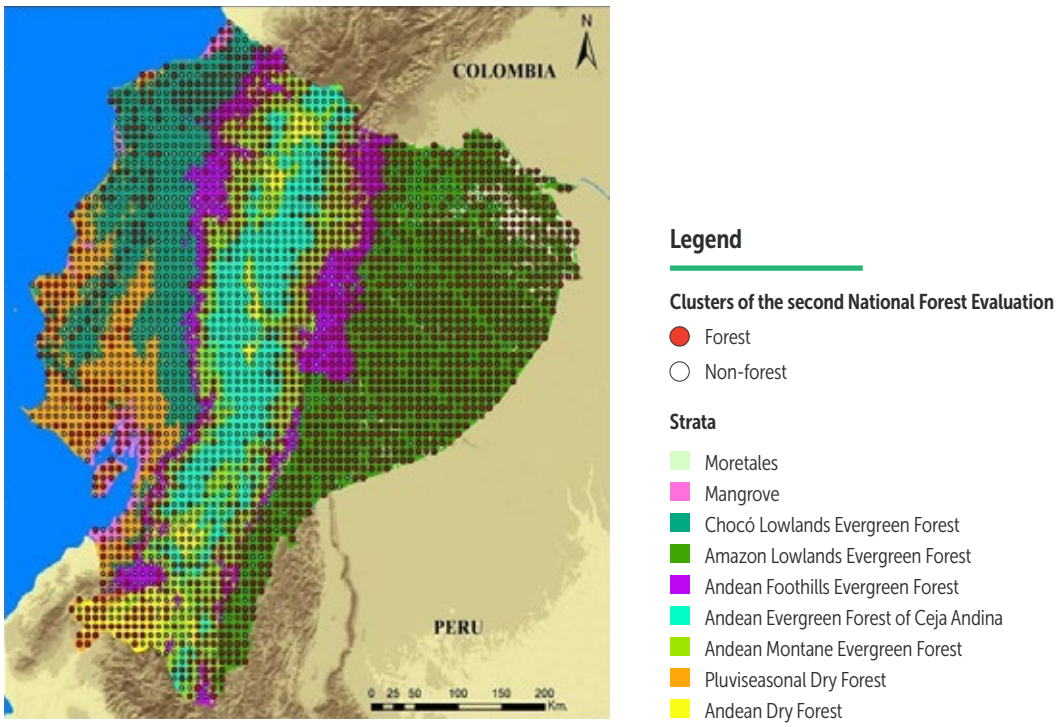
Volume was estimated using general equations (Table 13.7), given the absence of specific formulas due to the high diversity of trees in native forests. The calculation was made at the individual tree level based on diameters, commercial height and a 0.7 form factor, as provided in the national forestry regulations.

Biomass

Biomass was calculated from volumetric results (Table 13.7), using wood density values obtained from the FAO wood density list (Zanne *et al.*, 2009) and considering two scenarios: trees without botanical identification (0.52 g/cm³ weighted average of all species reported for the country) and trees with some level of identification (average for family, genus or species).

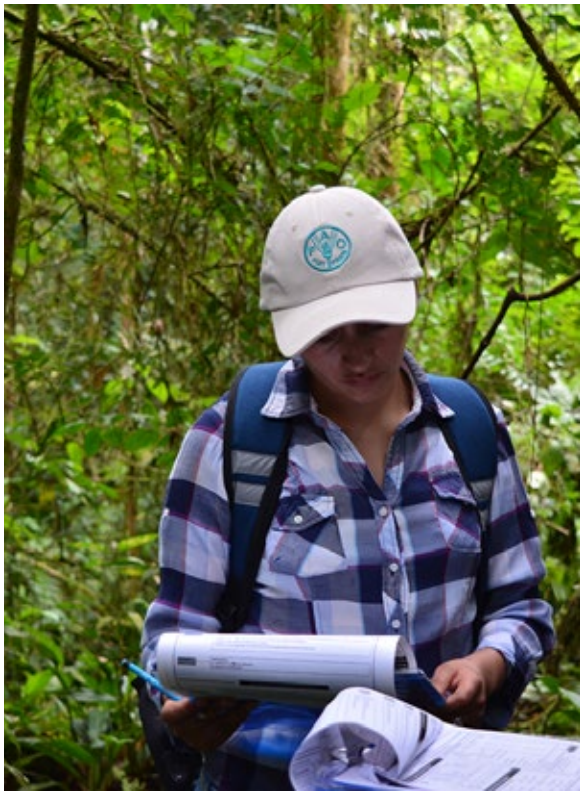
FIGURE 13.2

Map of strata and sample distribution for the second national forest assessment



The boundaries shown and the names and designations used on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any countries, territories, cities, areas, authorities, or delimitation of their frontiers or boundaries. Dotted lines on maps represent approximate boundaries for which there may not yet be full agreement.

Source: **MAE.** 2018. *Evaluación Nacional Forestal: Marco conceptual.* Quito. Internal document.



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The data were then grouped into living trees, standing dead trees (with and without branches), and palms and stumps. Equations proposed by Chave *et al.* (2005) were used for the first and second groups, classifying the strata according to vegetation type. For the third group, regional allometric equations were used for palms and volumetric equations were used for stumps.

TABLE 13.6

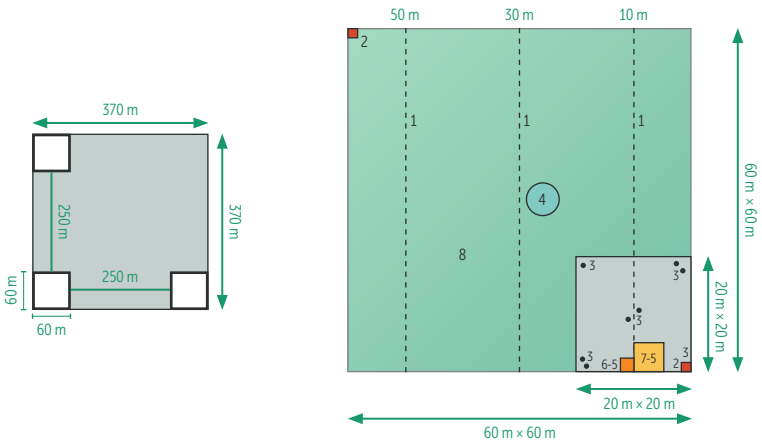
Sampling subunit characteristics

No.	Variable	Cycle	Method (quantity)	Dimensions	Criterion
1	**Dead wood**	1	Transect (1)	30 m	≥ 10 cm in diameter i
		2	Transect (3)	60 m	≥ 10 cm in diameter i
2	**Leaf litter and debris**	1	Quadrant (2)	50 cm × 50 cm	≤ 10 cm in diameter at breast high (DBH) and > 2 mm DBH
		2			
3	**Organic carbon and rootlets** **Bulk density** **Field capacity**	1	Known volume cylinder (5 / 3)	100 cm^3	10 cm, 20 cm, 30 cm and up to 60 cm in depth
		2			
4	**Tree regeneration**	1	Circular plot (1)	3.98 m (radius)	≤ 30 cm high and ≤ 10 cm DBH (8 strata)
		2			≤ 30 cm high and ≤ 5 cm DBH (BSVCA)
5	**Understorey and non-forest biomass**	1	Destructive plot (1)	2 m × 2m (8 strata)	≤ 10 cm DBH
		2		5 m × 5 m (dry forests)	
6	***Chusquea* biomass**	1	Quadrant (1)	2 m × 2 m	Number of stems
		2			
7	***Guadua* biomass**	1	Quadrant (1)	5 m × 5 m	10 stems
		2			
8	**Living trees, dead standing trees and stumps**	1	Plot (1)	20 m × 20 m	≥ 10 cm DBH
			Plot (2)	60 m × 60 m	≥ 20 cm DBH
		2	Plot (1)	60 m × 60 m	≥ 10 cm DBH

Source: Prepared by the authors.

FIGURE 13.3

Design and distribution of nested plots in the second national forest assessment



Note: 1: dead wood; 2: leaf litter and debris; 3: soil organic carbon, bulk density, field capacity; 4: tree regeneration; 5: understorey and non-forest biomass; 6: *Chusquea* biomass; 7: *Guadua* biomass; 8: living trees, dead standing trees and stumps.

Source: **MAE.** 2018. *Evaluación Nacional Forestal: Marco conceptual.* Quito. Internal document.

TABLE 13.7

Equations used for volume and biomass calculations

Variable	Equation	Reference
Total volume (m^3/ha)	$Vol\ t = \left(\left(\frac{3.1416}{4}\right) \times \left(\left(\frac{DBH}{100}\right)^2\right)\right) \times H \times 0.7$	MAE and FAO (2014a)
Commercial volume (m^3/ha)	$Vol\ c = \left(\left(\frac{3.1416}{4}\right) \times \left(\left(\frac{DBH}{100}\right)^2\right)\right) \times Hc \times 0.7$	MAE and FAO (2014a)
Biomass (kg)	**Living trees and standing dead trees** Allometric equations of Chave *et al.* (2005) Discounts apply to dead trees BSA and BSP $B = \rho \times exp\ (-1.499 + (2.148 \times Ln\ (DBH)) + (0.207 \times Ln\ (DBH)^2) - 0.0281 \times Ln\ (DBH)^3)$	MAE and FAO (2014a)
	BSVAM, BSVCA, BSVTBM and BSTBCH $B = \rho \times exp\ (-1.499 + (2.148 \times Ln\ (DBH)) + (0.207 \times Ln\ (DBH)^2) - 0.0281 \times Ln\ (DBH)^3)$	Chave *et al.* (2005)
	BSVAPM and Mo $B = \rho \times exp\ (-1.239 + (1.98 \times Ln\ (DBH)) + (0.207 \times Ln\ (DBH)^2) - 0.0281 \times Ln\ (DBH)^3)$	
	M $B = \rho \times exp\ (-1.349 + (1.98 \times Ln\ (DBH)) + (0.207 \times Ln\ (DBH)^2) - 0.0281 \times Ln\ (DBH)^3)$	
	Palms Seven regional equations for palms at the genus level	Goodman *et al.* (2013)
	Astrocaryum $AGB = 21.302 \times Hc$	
	Attalea $Ln\ (AGB) = 3.2579 + 1.1249 \times Ln\ (Hc + 1)$	
	Euterpe $AGB = -108.81 + 13.598 \times Hc$	
	Iriartea $Ln\ (AGB) = -3.483 + 0.94371 \times Ln\ (DBH^2 \times Hc)$	
	Mauritia $Ln\ (AGB) = 2.4647 + 1.3777 \times Ln\ (Hc)$	
	Mauritiella $AGB = 2.8662 \times Hc$	
	Oenocarpus $Ln\ (AGB) = 4.5496 + 0.1387 \times Hc$	
	General equation for *Arecaceae* $Ln\ (AGB) = -3.3488 + 2.7483 \times Ln\ (DBH)$	
	Stump Volumetric equation for stumps $B = \left(\frac{\pi}{4}\right) \times (DBH \times 0.001)^2 \times H \times \rho \times Fft$	

Notes: *AGB:* above-ground biomass; *B*: biomass; *DBH*: diameter at breast height; *Fft:* form factor equal to 0.7 per national regulation and 1 for stumps; *H:* height; *Hc:* commercial height; *Vol c:* commercial volume; *Vol t:* total volume; *ρ:* wood density; *π:* pi value. Pluviseasonal Dry Forest (BSP), Andean Dry Forest (BSA), Andean Foothills Evergreen Forest (BSVAPM), Andean Montane Evergreen Forest (BSVAM), Andean Evergreen Forest of Ceja Andina (BSVCA), Amazon Lowlands Evergreen Forest (BSVTBM), Chocó Lowlands Evergreen Forest (BSTBCH), Mangrove (M) and Moretales (Mo).

Source: **Chave, J., Andalo, C., Brown, S., Cairns, M.A., Chambers, J.Q., Eamus, D., Fölster, H.,** *et al. 2005. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. Oecologia*, 145: 87–99.; **Goodman, R.C, Phillips, O.L., Del Castillo Torres, D., Freitas, L., Tapia Cortese, S., Monteagudo, A. & Baker T.R.** 2013. Amazon palm biomass allometry. *Forest Ecology and Management, 310: 994–1004.;* **MAE & FAO. 2014a.** *Resultados de la Evaluación Nacional Forestal.* Quito.

13.6 RESULTS OF THE NATIONAL FOREST ASSESSMENT

The results presented below correspond to the first measurement cycle carried out between 2009 and 2013. The second cycle is currently in the initial measurement phase and thus a statistical estimate of the results is not yet possible.

Land area

The forest area for the 2008 forest and non-forest map corresponds to 11 363 287 hectares (ha).

Fifty-five percent of the forest cover corresponds to Amazon forest (BSVTBM), followed by 16 percent of montane forest (BSVAM) and 9 percent of foothill forest (BSVAPM) (Table 13.8).

Volume

As shown in Table 13.9, based on the minimum cutting diameter (MCD), the highest commercial volumes per hectare are concentrated in the following strata: Moretales (9), Amazon Lowlands (6) and Andean Foothills (4); the lowest volumes are found in the Dry Forest (2), Andean Dry Forest (1) and Ceja Andina (5) strata.

When considering the national regulations at species level and the MCD, as shown in Table 13.10, in certain strata, harvesting percentages exceed 50 percent of the exploitable volume above the MCD in relation to the total commercial volume, which suggests a considerable reduction of the exploitable volume in the first cutting cycle.

Considering legal restrictions such as slope, endangered species and MCD, the volumes show a reduction in the exploitable stock and underline the need to produce high-resolution, spatially explicit information for optimal monitoring. The results presented in Table 13.8 summarise the information obtained during the first cycle of the NFA.

Biomass

The biomass results for living trees, standing dead trees with branches and without roots, and stumps include the below-ground carbon values estimated with the generic equation of Chave *et al.* (2005), multiplied by the 0.24 factor of Cairns *et al.* (1997). In the case of palms, a generic equation was used, while for stumps it was assumed that they were fully rooted and thus they were treated as living trees. The values show a gradient at the strata level, with values ranging from 47.91 t/ha in Andean Dry Forest to 108.12 t/ha in Amazon Lowlands Evergreen Forest (MAE and FAO, 2014a).

The uncertainty values of the estimates (Table 13.8) demonstrate the need to improve the distribution and sampling size in the second cycle of the NFA, particularly in the strata of Moretales and Andean Evergreen Forest of Ceja Andina, on the upper limit of the forest with values higher than 20 percent.

TABLE 13.8

Results of the first national forest assessment (2009–2013)

Variable	Result	Description
Forest land area (1 000 ha)	Pluviseasonal Dry Forest (BSP) 399 323 ha (3.5%) Andean Dry Forest (BSA) 162 963 ha (1.4%) Andean Foothills Evergreen Forest (BSVAPM) 1 888 674 ha (16.6%) Andean Montane Evergreen Forest (BSVAM) 502 770 ha (4.4%) Andean Evergreen Forest of Ceja Andina (BSVCA) 1 079 697 ha (9.5%) Amazon Lowlands Evergreen Forest (BSVTBM) 6 293 513 ha (55.3%) Chocó Lowlands Evergreen Forest (BSTBCH) 465 706 ha (4.1%) Mangrove (M) 104 572 ha (0.9%) Moretales (Mo) 466 069 ha (4.1%)	Test with Moderate Resolution Imaging Spectroradiometer (MODIS) imagery at resolution of 250 m and 500 m, and a mosaic of Landsat satellite images developed by the University of Maryland in 2008 (MAE and FAO, 2014b) In parentheses: percentage of total forest in the country

TABLE 13.8 (CONTINUED)

Variable	Result	Description
Volume (m^3/ha)	Pluviseasonal Dry Forest (BSP) 33.7 Andean Dry Forest (BSA) 5.7 Andean Foothills Evergreen Forest (BSVAPM) 27.7 Andean Montane Evergreen Forest (BSVAM) 26.4 Andean Evergreen Forest of Ceja Andina (BSVCA) 14.5 Amazon Lowlands Evergreen Forest (BSVTBM) 21.7 Chocó Lowlands Evergreen Forest (BSTBCH) 28.9 Mangrove (M) 4.8 Moretales (Mo) 19.4	Commercial volume in m^3 with bark, starting from a minimum of 10 cm diameter at breast height (DBH)
Biomass (t/ha)	Pluviseasonal Dry Forest (BSP) 31.62 ±2.37 Andean Dry Forest (BSA) 36.56 ±3.20 Andean Foothills Evergreen Forest (BSVAPM) 96.74 ±5.05 Andean Foothills Evergreen Forest (BSVAPM) 110.03 ±5.55 Andean Foothills Evergreen Forest (BSVAPM) 85.68 ±10.35 Amazon Lowlands Evergreen Forest (BSVTBM) 140.93 ±4.26 Chocó Lowlands Evergreen Forest (BSTBCH) 68.68 ±3.04 Mangrove (M) 63.48 ±5.45 Moretales (Mo) 64.71 ±6.59	Estimates, statistics and confidence interval for above-ground biomass carbon and roots (t/ha) for living trees, standing dead trees and stumps (including palms)

Source: Prepared by the authors.

TABLE 13.9

Average commercial volume per hectare

	Stratum	Exploitable (m^3/ha)	Unexploitable (m^3/ha)
1	**Andean Dry Forest**	39.3	21.6
2	**Pluviseasonal Dry Forest**	37.8	15.8
3	**Andean Montane Evergreen Forest**	56.2	68.2
4	**Andean Foothills Evergreen Forest**	70.5	134.0
5	**Andean Evergreen Forest of Ceja Andina**	31.2	33.4
6	**Amazon Lowlands Evergreen Forest**	70.9	167.9
7	**Chocó Lowlands Evergreen Forest**	47.7	97.9
8	**Mangrove**	6.8	129.3
9	**Moretales**	71.6	215.1

Notes: Exploitable: tree species mentioned in the Forest Regulations and tree species not mentioned or not identified, which are above the minimum cutting diameter (MCD).
Unexploitable: refers to all named and unnamed species in the Forest Regulations, or unidentified species that are below the MCD.
Source: Prepared by the authors.

TABLE 13.10

Commercial volume per stratum, in each of the categories identified by the Forest Regulations

	Stratum	UA (m^3/ha)	UB (m^3/ha)	UA (% of total unspecified)	SA (m^3/ha)	SB (m^3/ha)	SA (% of total specified)
1	**Andean Dry 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 Evergreen Forest of Ceja Andina**	16.5	22.0	42.9	14.6	11.4	56.2
6	**Amazon Lowlands Evergreen Forest**	34.6	134.7	20.4	36.3	33.2	52.2
7	**Chocó Lowlands 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	**Moretales**	34.3	188.7	15.4	37.3	26.4	58.6

Notes: SA: specified above the minimum cutting diameter (MCD); SB: specified below the MCD; UA: unspecified above the MCD; UB: unspecified below the MCD.
Source: Prepared by the authors.

13.7 IMPLEMENTATION AND QUALITY CONTROL

Data collection is monitored by a multidisciplinary technical team from MAATE, which is responsible for analysing institutional information needs, updating technical documentation and applying the procedures that govern the NFE. These procedures can be summarised as follows:

- Planning: includes forming and organizing teams, establishing civilian, governmental and security contacts, drawing up service contracts, and preparing logistics and training.
- Data collection: this involves collecting data and samples in each cluster plot, following the protocols and instructions in the field manual and applying the knowledge acquired from the training.
- Supervision: in order to ensure that the information generated from the NFA is complete, correct and accurate, three steps are taken: (i) accompaniment, provided to the field teams by an NFA Technical Unit; (ii) office supervision (cold check), exploratory analysis of data received by the field teams, which makes it possible to establish alerts and implement corrective actions or remeasurements if necessary; and (iii) field supervision, which consists of remeasuring 10 percent of the sampling units to verify, compare and calibrate the information collected.
- Processing: at this stage, statistical criteria are applied to clean and purge data in order to produce meaningful information by validating and classifying data.
- Data analysis: this is the statistical process to estimate the values of the NFA variables, their accuracy and precision at the national scale or within a dataset (stratum or domain), depending on the information requirement for forest resource management.
- Reporting and dissemination: corresponds to knowledge management aimed at disseminating information at various levels and making it available for decision-making.

Quality assurance of the information is based on protocols on field activities and the use of specific tools. It falls under the responsibility of the team leaders, who are in charge of the forms and the field samples, as well as the coordination of activities with the NFA Technical Unit.

The training of the field teams aims to standardize knowledge on the methods and the use of tools and NFA manuals and guides.

Regarding data collection, once they are recorded on physical forms, the data are entered into the NFE database stored in the Open Foris Collect (OFC) platform, developed by FAO for forest inventories (MAE, 2013b). This database contains built-in validators and safeguards to minimise typing errors, gaps and out-of-range values. Data entry staff are trained in the use of the OFC survey and receive a user manual; in addition, the NFA Technical Unit provides support to make corrections in near real time.

In accordance with the data collection schedule, specific moments are established for supervision by the Technical Unit, with the aim to implement corrective measures, if necessary, and to subsequently accept or reject the set of cluster plots assigned to each team.

Once the data collection phase has been completed, the data are organized and cleaned using general procedures for data cleaning and by defining classification criteria, thereby detecting errors such as out-of-range values, outliers in the relationship between variables, and misallocated categories or logical relationships between variables.

The original and cleaned data are backed up, and files are created with the reports of the supervision process.

13.8 OTHER RELEVANT VARIABLES COLLECTED

The NFA has a multipurpose approach that focuses on forest productivity and biodiversity, the state of the forest, and carbon stock estimates. Its purpose is to generate information on forest resources on a periodic basis in order to guide decision-making on forest land management and administration, as well as the development of public policies.

The NFA collects information on 73 response variables and 21 classification variables. The majority of variables correspond to descriptions of forest structure and composition; in addition, information is collected to support logistics, measurement cycle planning and monitoring processes, tree regeneration, presence of alien species, productivity of prioritised species, land area of zones covered by *Chusquea* and *Guadua* bamboos, soil characteristics, and local perspectives on land tenure and use of forest resources.

Given its high floristic diversity, the country's taxonomic information and associated samples are noteworthy; these are kept at the National Herbarium of Ecuador for use in taxonomic and ecological studies, among other uses.

Likewise, the data obtained contribute to the National Forest Monitoring System, as established in article 342 of the Regulations to the Organic Code on the Environment for the assessment of the National Forest Heritage; they also contribute to the valuation of environmental services.

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13.9 FUTURE PERSPECTIVES

The implementation of forest governance requires more detailed, accurate and precise data, which becomes a true challenge when incorporating the characteristics of highly diverse areas, monitoring conservation values, and measuring changes in carbon stocks, the dynamics of land use change, the impact of human activities and implementation of public policy, among other aspects of the NFA, all while balancing cost and effectiveness.

This requires the inclusion of new technologies and approaches to data collection, while maintaining the comparability of data across multiple inventories.

The second NFA currently underway has introduced changes in the way some variables are measured and classified. The sampling of trees has been intensified due to the need for more information on species and their classification by diameter class in order to assess the productivity of the forests and the floristic richness of the trees. Dead wood sampling was also intensified in order to improve the estimates of this carbon pool and the measurement of fuels related to fire patterns. In addition, the location of the regeneration plot was modified to better link the sampling site information with species turnover.

In the long term, new technologies will be explored to assess forests and strength links with the National Forest Monitoring System in order to have models of biomass, volume, distribution of species of interest, and other variables related to spatial information on areas for sustainable use, fragmentation, ecosystems, and other forest management elements. An important aspect for species with high biodiversity is the taxonomic identification of trees, given the considerable effort required to obtain a botanical sample. To this end, the development of a methodology to improve the quality of the botanical identity of trees is being analysed.

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Chapter 14

EL SALVADOR

NATIONAL FOREST INVENTORY OF EL SALVADOR

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14.1 HISTORICAL OVERVIEW OF NATIONAL FOREST INVENTORIES IN EL SALVADOR

Recognising the importance of quantifying and qualifying the forest resources of El Salvador, the first National Forest Inventory (NFI) was launched on 2 December 2002. The Inventory of Forest Resources of El Salvador project was financed by the Special Fund of Resources from the Privatisation of the National Telecommunications Administration (Fondo Especial de los Recursos provenientes de la Privatización de ANTEL – FANTEL, according to its acronym in Spanish) (MAG, 2003a).

The project was implemented by the General Directorate of Forest Management, Watersheds and Irrigation (Dirección General de Ordenamiento Forestal, Cuencas y Riego in Spanish) of the Ministry of Agriculture and Livestock (MAG). The outputs of this inventory were a map of the forest types, tables on the volume of main species, and the measurement of plots to develop the corresponding estimates.

The three main forest types considered in the first NFI were mangrove forest, broadleaved forest and coniferous forest. Broadleaved forest was further subdivided into six subtypes: moist lowland forest, moist deciduous forest, dry forest, cloud forest, evergreen or coffee shade forest, and mixed forest (Table 14.1).

The design of the inventory was stratified with randomised distribution of plots in each stratum. The sample size calculation was proportional to the area of each stratum (proportional allocation). Each stratum corresponded to a forest subtype (MAG, 2003a).

The boundaries of each forest type and subtype were identified and delimited manually in geographic information system (GIS) programmes, using satellite imagery (IRS panchromatic images from 2001 with a 6-metre (m) spatial resolution and Ikonos multispectral imagery from 2001). It should be noted that a forest concept was not defined for this NFI.

The sampling unit (SU) design was nested with circular plots in all forest subtypes. The SUs were distributed in each subpopulation in two phases: 330 SUs were distributed during the initial pre-sampling phase and 106 SUs during the subsequent sampling phase, resulting in a total of 436 SUs established at national level (Table 14.1).

The above-mentioned forest inventory was not finalised due to various reasons. Nevertheless, it has yielded some valuable results for relevant use by MAG.

Between 2016 and 2018, a second project was implemented to finalise the NFI. One of the improvements made during this second cycle was to provide a definition of forest starting from the initial planning phase. The general objective was to quantify and evaluate the state of El Salvador's various types of forest types, including shade-grown coffee, as a decision-making tool for their protection, conservation and/or sustainable management.

The territorial scope of the NFI was the forest land area of El Salvador, divided during Phase I (pre-sampling) into six vegetation strata: secondary forest, evergreen forest, deciduous/semi-deciduous forest, shade-grown coffee plantation, coniferous forest and mangrove forest. However, in Phase II (sampling) the area was divided into four grouped strata by merging the secondary forest, mature evergreen forest and mature deciduous/semi-deciduous forest into the broadleaved forest stratum (MARN, 2018a).

The population under study was considered statistically infinite (MARN, 2018a), based on the forest map generated with RapidEye satellite imagery from 2011 with a 5 m (4.90 m) spatial resolution. Although the images used were from 2011, the forest map was produced in 2014 and then corrected and adjusted to the forest concept in 2017.

A summary of the national forest inventories conducted to date is presented in Table 14.1.

14.2 TERMS AND DEFINITIONS RELEVANT TO THE IMPLEMENTATION OF THE NATIONAL FOREST INVENTORY

The NFI used the definition of forest described in the National REDD+ (Reducing Emissions from Deforestation and Forest Degradation) Strategy of El Salvador, which was discussed in several workshops held with public and private institutions in 2016. There is also a definition of each type of forest, such as secondary forest, mature evergreen forest, mature deciduous/semi-deciduous forest, shade-grown coffee plantation, coniferous forest and mangrove forest.

The strata defined for the NFI included the shade-grown coffee plantation, which is the only stratum considered as "other land" in reports submitted to the Global Forest Resources Assessment (FRA) of the Food and Agriculture Organization of the United Nations (FAO). It should be noted that no strata were measured in the FRA category "other wooded land."

Table 14.2 details the most important definitions used in the NFI to determine the scope of the required products.

14.3 SAMPLING DESIGN

The NFI's scope of study corresponds to El Salvador's forest and shade-grown coffee areas, with the exclusion of the *exbolsones* territory (areas bordering Honduras where problems with border demarcation have been reported).

According to the 2011 land cover and land use mapping, and establishing the minimum forest area at 0.5 hectares (ha), there are 606 541.78 ha of forest in the country (28.76 percent of the national territory), to which 174 834 ha of shade-grown coffee plantations must be added (8.29 percent of the national territory), totalling 781 375.78 ha (37.05 percent of the national territory). The latter is the NFI study area considered for the calculation of the total NFI results (MARN, 2018a).

The sampling design is non-aligned systematic stratified sampling: the distribution of the SUs was balanced, with equal-sized segments defined by spatial filling curves based on fractals (Lister and Scott, 2008). One SU per segment was randomly selected (Figure 14.1) (MARN, 2018a). Each stratum corresponds to a different type of vegetation (MARN, 2018a).

TABLE 14.1

Historical overview of national forest inventories in El Salvador

Inventory cycle	Implementation period	Scale	Sampling design	Number of sampling units
NFI 1	2002–2004	National	Stratified, with random plot distribution in each stratum and a sample size proportional to the area of each stratum	436
NFI 2	2017–2018	National	Stratified, with non-aligned systematic sampling	319

Source: Prepared by the authors with data from **MAG (Ministry of Agriculture and Livestock).** 2004. *Informe del Sexto Trimestre: Inventario de los Recursos Forestales de El Salvador.* Proyecto FANTEL/FORESTAL-001/2002. San Salvador.; **MARN (Ministry of Environment and Natural Resources).** 2018a. *Inventario Nacional de Bosques de El Salvador (INB) 2018.* Preparation of El Salvador's Readiness proposal for the Forest Carbon Partnership Facility. San Salvador.

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TABLE 14.2

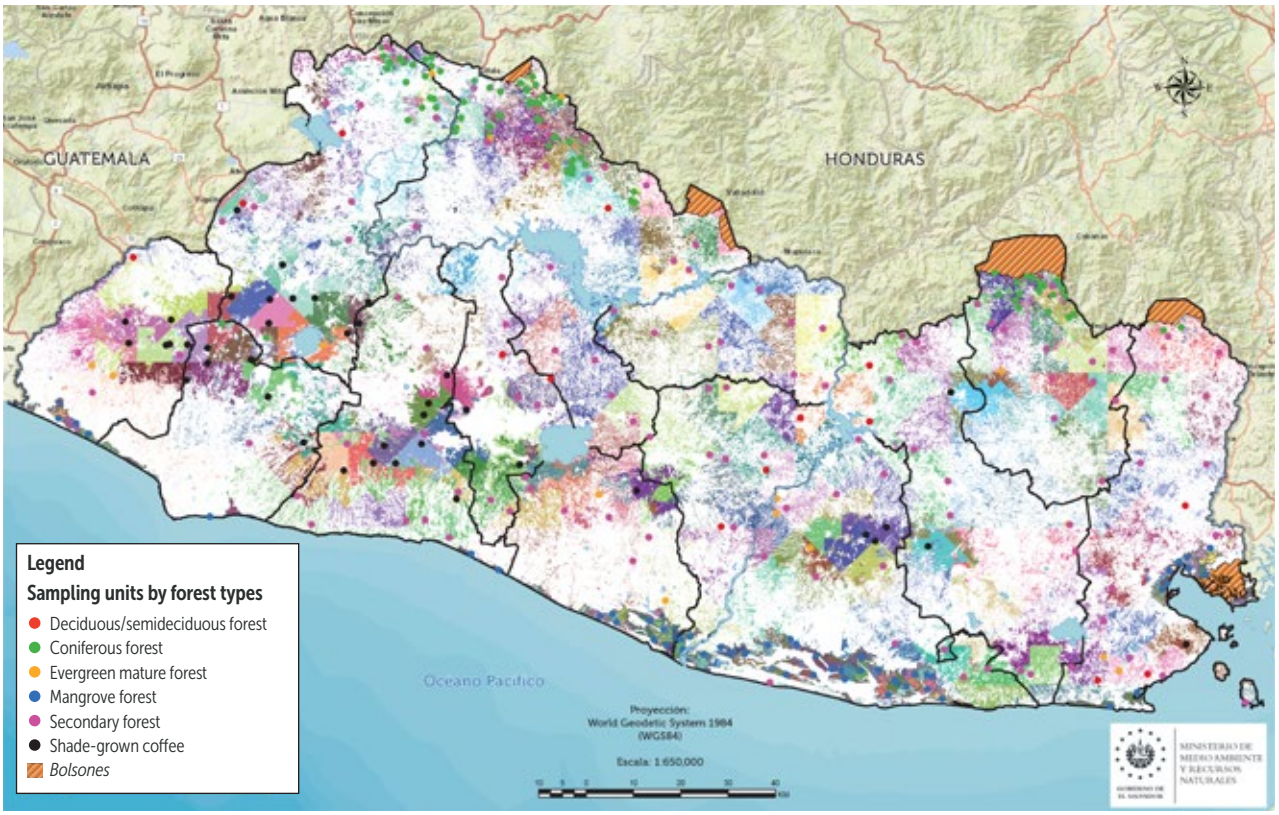
Summary of definitions used in the implementation of the National Forest Inventory

Term	Definition	Variables and thresholds
Forest	Land area spanning a minimum of 0.5 ha, with a canopy cover of 30 percent or more and trees able to reach a minimum height of 4 m at maturity *in situ*. Land that is predominantly under agricultural or urban land use is not included.	Minimum land area: 0.5 ha Canopy cover: ≥ 30% Tree height: ≥ 4 m
Other land	Shade-grown coffee: woody vegetation with two storeys; the first storey dominated by the coffee crop (lower story), and the second dominated by trees (upper story), with a canopy cover of more than 30 percent. In some cases, there may be three storeys, though usually the second and third storeys are tree cover.	Minimum land area: 0.5 ha Canopy cover: ≥ 30% shrub cover in coffee plantations Tree height: ≥ 4 m
Volume	Total volume (m^3): living and dead trees with a diameter at breast height (DBH) greater than or equal to 2 cm. Bark is included.	Minimum diameter DBH: ≥ 2 cm
Biomass	Above-ground biomass: the dry above-ground biomass (kg) of trees. It includes herbaceous biomass and living stumps. Below-ground biomass: estimated for the different forest types, using the above-ground biomass estimate as an independent variable. Dead wood biomass: lying dead woody materials, including stumps and dead trees. Dead leaf litter biomass: dead non-woody biomass, which includes both dead leaf litter and dead understorey components.	Above-ground biomass: trees with DBH ≥ 2 cm Includes herbaceous biomass Below-ground biomass: not directly measured Dead wood biomass: minimum diameter of 2 cm Stumps with height ≥ 50 cm and standing dead trees are included Dead litter biomass: 1.9 cm in maximum diameter Soil organic matter: includes organic carbon at a depth of 20 cm, except in mangrove forests, which is at a depth of 100 cm

Source: **MARN.** 2018a. *Inventario Nacional de Bosques de El Salvador (INB) 2018.* Preparation of El Salvador's Readiness proposal for the Forest Carbon Partnership Facility. San Salvador.; **MARN.** 2020a. *Manual de campo: diseño de parcela y medición de variables de sitio y dasométricas.* San Salvador.

FIGURE 14.1

Fractal map and distribution of sampling units



The boundaries shown and the names and designations used on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any countries, territories, cities, areas, authorities, or delimitation of their frontiers or boundaries. Dotted lines on maps represent approximate boundaries for which there may not yet be full agreement.

Source: Prepared by the authors.

TABLE 14.3

Characteristics of the National Forest Inventory sampling design

Name of the region	Total area (1 000 ha)	Number of sampling units			Total number of sampling units
		Forest	Other wooded land	Other land	
National	2 109	279	n/a	40	319

Note: n/a: not applicable.

Source: **MARN.** 2018a. *Inventario Nacional de Bosques de El Salvador (INB) 2018.* Preparation of El Salvador's Readiness proposal for the Forest Carbon Partnership Facility. San Salvador.

The sampling intensity in each stratum was defined such that the most unfavourable variable had a sampling error of up to 15 percent, at a confidence level of 95 percent (MARN, 2018a).

This methodology was chosen because of the need to address the representation of smaller forest areas. The pattern of the country's forest area is characterized by its fragmentation, thus ensuring that any patch of forest can be chosen as a sampling area, irrespective of its size.

The development of El Salvador's NFI was organized in two phases. The objective of Phase I was to provide data for sample size calculation, assess logistics, validate protocols, determine yields and address contingencies. Data from Phase I were used in Phase II to recalculate the final sample size to meet the pre-established error of 15 percent per stratum. In total, 319 SUs were measured in the two phases (Table 14.3).

Since no previous inventory was available, Phase I was key to understanding the characteristics of the forest crop and making technical decisions, such as merging the initial strata of secondary forest, mature evergreen forest and deciduous/semi-deciduous forest into a single stratum called broadleaved forest (MARN, 2020c).

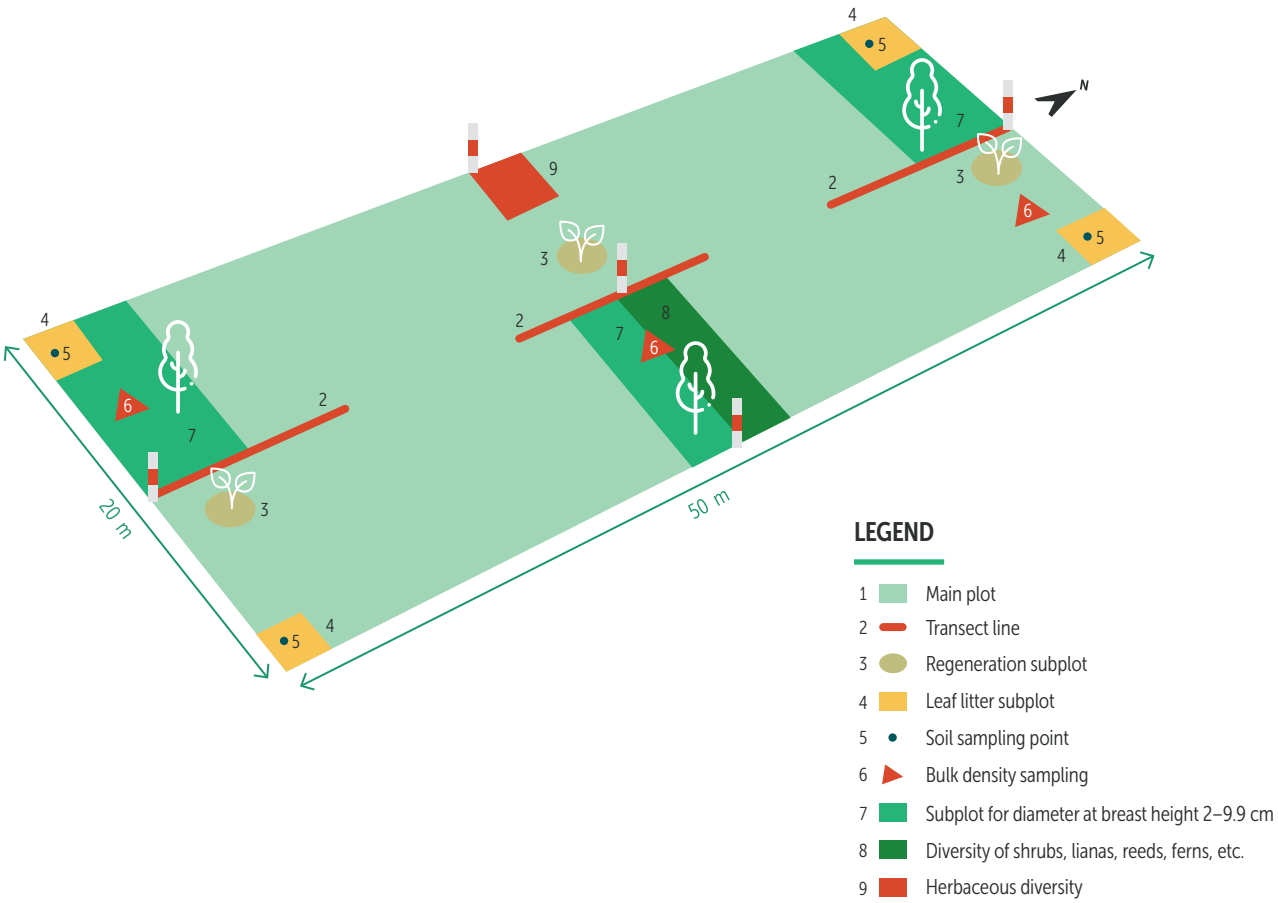
An area bordering Honduras referred to as *exbolsones* was not sampled. Plots that were randomly located in the *exbolsones* areas were redistributed elsewhere to avoid incidents that would put the physical integrity of the crews at risk, given that there are border conflicts in these areas that require military presence. Therefore, the NFI estimates exclude these areas.

The shade-grown coffee stratum was included in this NFI due to the following reasons:

- It covers an area of 8.29 percent of the national territory (according to the map adjusted in 2017).
- It is one of the agroecosystems with the greatest contribution in firewood and commercial timber for Salvadoran industries.
- It is located in soils with rugged topography and often at the headwaters of micro-watersheds, such as water recharge zones.
- It is considered that coffee areas that are unmanaged for more than five years become secondary forest structures.

FIGURE 14.2

Design of nested sampling unit 1 for the National Forest Inventory of El Salvador



Source: **MARN.** 2020a. *Manual de campo: diseño de parcela y medición de variables de sitio y dasométricas.* San Salvador.

14.4 SAMPLING UNIT DESIGN

Three types of SU were established in the NFI of El Salvador (MARN, 2020a): one for evergreen forest, deciduous forest, secondary forest and coniferous forest, one for shade-grown coffee, and one for mangrove forest.

The SU for mature evergreen forest, mature deciduous forest, secondary forest and coniferous forest consisted of an individual plot of 1 000 m² (20 m by 50 m) with the main axis of symmetry oriented from north to south (see Figure 14.2 and Table 14.4).

The SU applied in the shade-grown coffee stratum was similar to the previous one, with the following differences: i) the length was 125 m, and ii) coffee plants were measured in the central sampling subplot, in addition to measuring trees with DBH between 2 cm and 9.9 cm.

The third type of SU was used only in the mangrove forest stratum; it consisted of five circular plots of 200 m², within which the subplots described in Figure 14.3 and Table 14.5 were established. The circular subplots were spaced 20 m apart.

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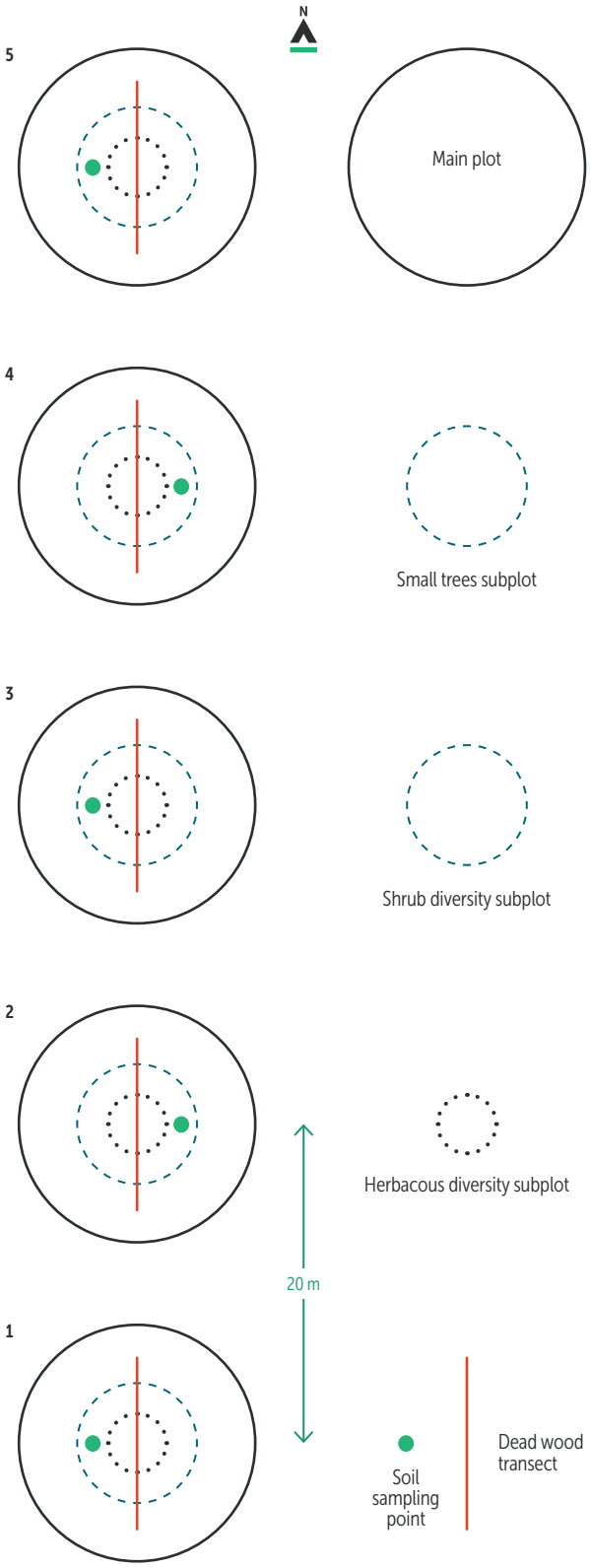
FIGURE 14.3

Sampling unit design for mangrove forest



Source: Adapted from **MARN.** 2020a. *Manual de campo: diseño de parcela y medición de variables de sitio y dasométricas.* San Salvador.

TABLE 14.4

Characteristics of the rectangular sampling unit

Name	Characteristics	Number of units	No. in Figure 14.2
Main plot	Rectangle measuring 20 m × 50 m (1 000 m^2) to measure trees ≥ 10 cm diameter at breast height (DBH)	1	1
Small tree subplot	Rectangle measuring 5 m × 10 m (50 m^2) to measure trees ≥ 2 cm DBH and ≤ 9.9 cm DBH	3	7
Regeneration subplot	Circle with 1 m radius (3.14 m^2) to measure trees ≤ 1.9 cm DBH and ≥ 30 cm in height	3	3
Subplot of shrub diversity, lianas, reeds, ferns and others	Rectangle measuring 2.5 m × 10 m (25 m^2); number of shrubs, lianas, reeds, ferns, bamboos and others	1	8
Subplot of herbaceous diversity	Square of 1 m × 1 m (1 m^2) and number of herbaceous specimens	1	9
Subplot of leaf litter and herbaceous biomass	Square sampling frame of 0.5 m × 0.5 m (0.25 m^2)	4	4
Dead wood biomass transect	A 10 m long line over which intersections with lying dead woody materials are assessed	3	2
Soil carbon sampling point	Point of 20 cm in depth	4	5
Sampling point for bulk density of soil	Bulk density of soil	3	6

Source: **MARN.** 2020a. *Manual de campo: diseño de parcela y medición de variables de sitio y dasométricas.* San Salvador.

TABLE 14.5

Characteristics of sampling units for mangrove forest

Name	Characteristics	Units per subplot	Units per plot
Main plot	Circle of 7.98 m radius (200 m^2) to measure trees ≥ 10 cm diameter at breast height (DBH)	1	5
Small tree subplot	Circle of 3 m radius (28.27 m^2) to measure trees ≥ 2 cm DBH and ≤ 9.9 cm DBH	1	5
Regeneration subplot	Circle of 1 m radius (3.14 m^2) to measure trees ≤ 1.9 cm DBH and ≥ 30 cm high	1	5
Subplot of shrub diversity, lianas, reeds, ferns and others	Circle of 3 m radius (28.27 m^2) for shrubs, lianas, reeds, ferns, bamboos and others in the same small tree subplot	1	5
Subplot of herbaceous diversity	Circle of 1 m radius (3.14 m^2) to cut herbaceous in the same regeneration subplot	1	5
Dead wood transect	Line measuring 10 m in length to measure lying dead wood	1	5
Soil sampling point	Point of 100 cm in depth (two samples per point, the first at 0–50 cm and the second at 50–100 cm)	1	5
Sampling point for bulk density of soil	Two samples per point (the first at 20–25 cm and the second at 70–75 cm)	1	5

Source: **MARN.** 2020a. *Manual de campo: diseño de parcela y medición de variables de sitio y dasométricas.* San Salvador.

14.5 VOLUME AND BIOMASS CALCULATION

A comprehensive data management system was developed to process NFI data in a flexible and agile way (MARN, 2018a). This system was made up of the components depicted in Figure 14.4.

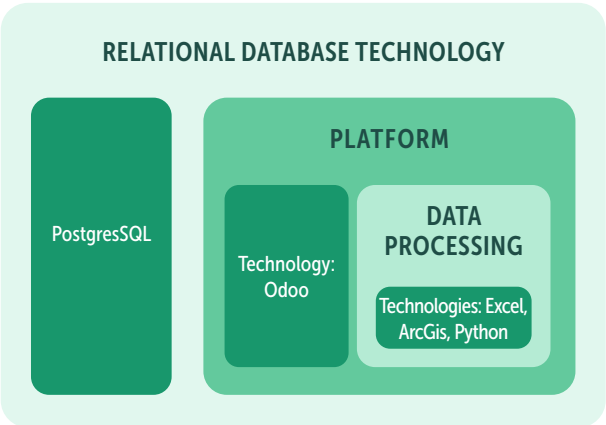
An open access PostgreSQL relational database was developed for the storage, processing and analysis of the collected data. This technology, which is widely established and used worldwide, enabled the process of data planning, data entry, review, validation, evaluation, finalisation and delivery. It was built to provide a high level of versatility and speed in performing complex queries. Data were stored and can be exported to Excel or Access. The relational database was managed from dBeaver software (MARN, 2018a).

The database was an important part of data processing for simple queries. For more complex processing, the queries were supported by the following technologies:

- Excel with the XLSTAT add-in, for statistical analysis of errors and obtaining height–diameter relationships, analysis of variance (ANOVA) calculations, among others.
- Python to develop the plot location algorithms and other back-up calculations.
- The ArcGIS package for broad spatial analysis. Geostatistical techniques for the interpolation of variables were performed with the Geostatistical Analyst extension. A model was also implemented with Model Builder to facilitate the location of Phase II plots, and for the management of the geospatial component in terms of field mapping, plot relocations, map editing, etc.

FIGURE 14.4

Diagram of the comprehensive data management system



Source: **MARN.**2018a. *Inventario Nacional de Bosques de El Salvador (INB) 2018.* Preparation of El Salvador's Readiness proposal for the Forest Carbon Partnership Facility. San Salvador.

In addition, a platform to enter and organize field data was used, using Odoo technology. A second platform for results was developed using Pentaho technology (MARN, 2018a).

The Pentaho platform was used to create an information dashboard with business intelligence capabilities to structure the different products generated for the NFI. This platform allowed for easy consultation, comparative analysis and interpretation of real-time results, through direct query to the database in PostgreSQL. This means that if data are adjusted, added or complemented in the future, the results at plot and stratum-plot level will be automatically updated according to the new data entered. However, stratum- and country-level data will not be automatically updated because they have been produced from advanced statistical calculations that have not been automated in Pentaho (MARN, 2018a).

In order to record the field data processing and to apply the calculation of each variable, a calculation report was drafted and can be consulted for further methodological details (MARN, 2020d). Table 14.6 provides an overview of the equations used for the volume and biomass calculations.

The volume calculation varied with the different strata or even with the different species found in the plots. The volume calculation methodologies presented are divided as follows (MARN, 2020d):

- volume calculation methodologies for broadleaved forests;
- volume calculation methodologies for coniferous forests;
- volume calculation methodologies for shade-grown coffee plantations;
- volume calculation methodologies for mangrove forests.

Table 14.7 presents the equations used in each forest stratum for the calculation of height based on diameter.

TABLE 14.6

Equations used for volume and biomass calculations

Variables	Equation	Reference
Total volume (m^3)	**Broadleaved forest:** trees ≥ 2 cm DBH $V = BA \times height \times 0.70$	General formula (Ojeda, 1983)
	Coniferous forest: the formula is the same as the one used for broadleaved forest, but the form factor varies per species, as shown below: – *Cupressus lusitánica*: 0.47 form factor – *Pinus oocarpa*: 0.56 form factor – Other coniferous: 0.50 form factor – Broadleaved species: 0.70 form factor	– Johnson (2000) – Castaneda and Jelvez (1985) – Sánchez Páez *et al.* (2004) – Ojeda (1983)
	Mangrove forest: calculated in the same way as for the other broadleaved strata, but taking into account the following form factors: – *Rizophora sp.:* 0.50 form factor – *Avicennia germinans:* 0.46 form factor – *Laguncularia racemosa:* 0.45 form factor – Broadleaved species: 0.70 form factor	– Sánchez-Páez *et al.* (2004) – Vásquez (2000) – Vásquez (2000) – Ojeda (1983)
	Shade-grown coffee: the formula is the same as the one used for broadleaved forest	
	Where: *BA*: basal area *height*: height from base to apex *DBH*: diameter at breast height *V*: volume (m^3)	
Biomass (kg)	Above-ground biomass (kg) of trees ≥ 2 cm DBH **Broadleaved forest:** $B = 0.0509 \times \rho \times DBH^2 \times height$ Where: *B*: biomass in kg ρ: specific gravity in g/cm^3 *DBH*: diameter at breast height in cm *height*: total height in m	Chave *et al.* (2005)
	Coniferous forest *Cupressus lusitanica:* $B = 0.5266 \times DBH^{1.7712}$	FAO (2013)
	Other coniferous: $Ln\ B = -2.18352102 + 0.85091168 \times Ln\ (DBH^2 \times H)$ Where: *B*: biomass in kg *DBH*: diameter at breast height *H*: height from base to apex	Alberto and Elvir (2005)
	Shade-grown coffee For trees greater than ≥ 2 cm DBH, the same equation was used as for broadleaved forest. Since trees in coffee plantations are thinned out for light control, a reduction in the percentage of canopy biomass was made. The ratio of crown to total biomass was analysed in the literature, resulting in an average of 48.3%.	
	The following equations were used for calculating the biomass of coffee tree stumps and shoots: $B\ (stumps) = 0.1124 \times (DAB^2 \times h)^{0.5435}$ Where: *B*: stump biomass in kg *DAB*: diameter at the base in cm *h*: total height	Castellanos, Quilo and Pons (2010)

TABLE 14.6 (CONTINUED)

Variables	Equation	Reference
Biomasa (kg)	$B\ (shoots) = 0.1955 \times DBH^{1.648}$ Where: *B*: biomass in kg *DAB*: diameter at the base of the shoot in cm	Castellanos, Quilo and Pons (2010)
	Mangrove forest Two functions were used: Equation for *Rhizophora* genus species $B = 0.0375 \times (DBH^2 \times h)^{0.98626} \times \rho$ Other species (general equation) $B = 0.168 \times \rho \times DBH^{2.471}$ Where: *B*: biomass in kg ρ: specific gravity in g/cm^3 *DBH*: diameter at breast height (1.3 m) *altura*: total height in m	Howard *et al.* (2014)

Source: **Alberto, D.M. & Elvir, J.A.** 2005. Acumulación y fijación de carbono en biomasa aérea de Pinus oocarpa en bosques naturales de Cabañas, La Paz. *Tatascán*, 17(2): 1–12.; **Castañeda, F. & Jelvez, A.** 1985. Altura total, diámetro altura de pecho y factor de forma para Pinus oocarpa Shi en Siguatepeque, Honduras. *Turrialba*, 35(2): 151–154.; **Castellanos, E., Quilo, A. & Pons, D.** 2010. *Estudio de la línea base de carbono en cafetales.* Guatemala City, Centro de Estudios Ambientales, Universidad del Valle de Guatemala.; **Chave, J., Andalo, C., Brown, S., Cairns, M.A., Chambers, J.Q., Eamus, D., Fölster, H.**, *et al.* 2005. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia*, 145: 87–99.; **FAO.** 2013. GlobAllomeTree: Assessing volume, biomass and carbon stocks of trees and forests – Allometric equations. In: *GlobAllomeTree*.; **Howard, J., Hoyt, S., Isensee, K., Pidgeon, E. & Telszewski, M.**, eds. 2014. *Coastal blue carbon: Methods for assessing carbon stocks and emissions factors in mangroves, tidal salt marshes, and seagrass meadows.* Arlington (USA), Conservation International, Intergovernmental Oceanographic Commission of UNESCO & International Union for Conservation of Nature.; **Ojeda, W.** 1983. Factor de forma preliminar para seis familias de especies forestales tropicales. *Revista Forestal del Perú*, 11(1–2): 1–6.; **Johnson, H.** 2000. Funciones volumétricas para árboles en pie de ciprés (*Cupressus lusitanica Mill.*) en sistema de plantación pura. Valle Central, Costa Rica. Faculty of Earth and Marine Sciences, National University of Costa Rica. Bachelor's thesis.; **MARN.** 2020d. *Memoria de cálculo del Inventario Nacional de Bosque de El Salvador 2018.* San Salvador.; **Sánchez Páez, H., Ulloa Delgado, G.A. & Tavera Escobar, H.A.** 2004. *Manejo integral de los manglares por comunidades locales: Caribe Colombiano.* Doc. No. 20678. Bogota, Ministry of Environment, Housing and Territorial Development, National Forestry Research and Development Corporation (CONIF), and International Tropical Timber Organization (ITTO).; **Vásquez, J.L.** 2000. *Estructura de los bosques de mangle del Valle de los Cangrejos y el Riíto, delta del río Ranchería, Caribe Colombiano*. National University of Colombia, Medellín. (Thesis).

TABLE 14.7

Equations used for the calculation of the height–diameter ratio

Stratum	Equation proposed	Coefficient of determination (R^2)
Broadleaved forest	$height\ (m) = 1.3 + \dfrac{DBH}{(1.21914 + 0.0446 \times DBH)}$	0.825
Coniferous forests (only coniferous)	$height\ (m) = -0.0015 \times DBH^2 + 0.3499 \times DBH + 4.8565$	0.719
Coniferous forests (only broadleaved)	$height\ (m) = 1.3 + \dfrac{DBH}{1.46490 + 0.0417 \times DBH}$	0.849
Mangrove forest with buttress roots	$height\ (m) = -0.0056 \times DBH^2 + 0.7284 \times DBH + 1.9545$	0.890
Mangrove forest without buttress roots	$height\ (m) = 3.886 \times ln\ (DBH) - 0.5259$	0.790
Shade-grown coffee plantation, broadleaved shade trees	$height\ (m) = 1.3 + \dfrac{DBH}{1.43025 + 0.0440 \times DBH}$ Where: *DBH*: diameter at breast height	0.830

Source: **MARN.** 2020d. *Memoria de cálculo del Inventario Nacional de Bosque de El Salvador 2018.* San Salvador.

14.6 RESULTS OF THE NATIONAL FOREST INVENTORY

The final NFI report provides the most relevant results, based on the forest mapping produced in 2014 and with an accuracy of 91 percent (MARN, 2018a). The RapidEye satellite images of 2011 were used to apply the validated forest concept at national scale, without considering the *exbolsones*, yielding the following results: 606 541.78 ha of forest (28.76 percent of the national territory), 174 834.00 ha of shade-grown coffee plantations (8.29 percent of the national territory), for a combined total of 781 375.78 ha, equivalent to 37.05 percent of the national territory.

In Phase II, corresponding to the sampling phase of the NFI, this forest area was made up of three strata and/or forest types (see Figure 14.5): broadleaved forest with 551 729.63 ha (26.16 percent), coniferous forest with 17 715.01 ha (0.84 percent) and mangrove forest with 37 097.13 ha (1.76 percent).

Table 14.8 presents the forest area, volume and biomass as results of the NFI (MARN, 2018a); these include the definitive strata but exclude the *exbolsones* area.

TABLE 14.8

Results of the National Forest Inventory of El Salvador

Variable	Result	Description
Forest land area (broadleaved forest, coniferous forest and mangrove forest)	606.5 (28.76%)	Land area (1 000 ha) Land area ≥ 0.50 ha, with 91% accuracy
Land area of other land/ other land with tree cover (shade-grown coffee)	174.8 (8.29%)	Country percentage in brackets
Forest volume	162.97 (± 9.0)	Volume (m^3/ha) Trees ≥ 2 cm diameter at breast height (DBH)
Shade-grown coffee volume	133.50 (± 11.1)	Confidence limit in brackets at a 95% confidence level
Forest biomass (above-ground biomass)	93.94 (± 9.8)	Biomass (t/ha) Trees ≥ 2 cm DBH
Shade-grown coffee biomass	78.05 (± 11.4)	Confidence limit in brackets at a 95% confidence level

Source: **MARN.** 2018a. *Inventario Nacional de Bosques de El Salvador (INB) 2018.* Preparation of El Salvador's Readiness proposal for the Forest Carbon Partnership Facility. San Salvador.

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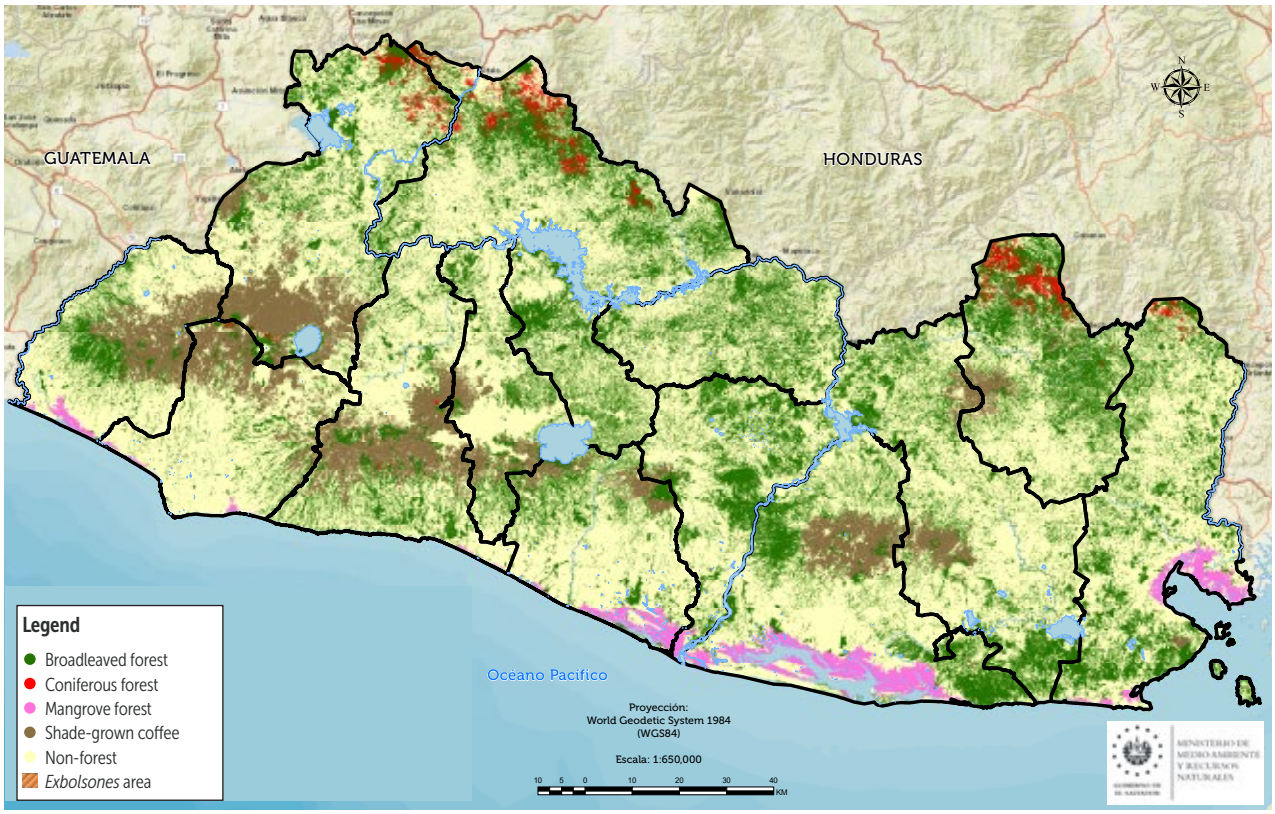
FIGURE 14.5

Map of distribution of forest types in El Salvador



The boundaries shown and the names and designations used on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any countries, territories, cities, areas, authorities, or delimitation of their frontiers or boundaries. Dotted lines on maps represent approximate boundaries for which there may not yet be full agreement.

Source: Prepared by the authors.

14.7 IMPLEMENTATION AND QUALITY CONTROL

The implementation of quality control and quality assessment was based on the protocols and methodology developed before and during the 2018 NFI, as follows:

- Field manual: plot design and measurement of site and dasometric variables;
- Quality control and evaluation protocols;
- Protocol for collection, identification of plant species and conservation of botanical samples;
- Protocols for measuring carbon in soil, leaf litter and herbaceous plants;
- Protocols for crew safety and logistics;
- Methodology for Phase I (pre-sampling) and Phase II (sampling);
- Calculation report of El Salvador's NFI of 2018.

Four crews and one additional quality control crew were recruited for the 2018 NFI. All crews received an intensive eight-day training, focusing on the understanding and use of the first six protocols and/or methodologies described above.

The quality control consisted of the following methods:

- Direct verification in the field to validate field crews' measurements and provide immediate feedback. While the target was to cover 3 percent of the SUs, a total of 3.2 percent was covered in the 2018 NFI (MARN, 2018b, 2020b).
- Indirect data verification in order to measure the accuracy of field crews' measurements and provide subsequent feedback. The goal to cover 2 percent of the SUs was met and exceeded, with a total of 2.2 percent covered (MARN, 2018b, 2020b).

In addition, an objective and quantitative evaluation of the quality of data was made. The stated goal was an additional 5 percent of the total SUs measured and approved by the quality control team (MARN, 2020b). These SUs were randomly selected. Approximately 2.8 percent was achieved under this category of quality control.

In summary, 8.2 percent of the targeted 10 percent for quality control and quality assessment of the SUs measured in the NFI was achieved (MARN, 2018b).

Another type of quality control was implemented by the 2018 NFI coordinator, wherein each piece of information that was entered for a given plot into the Odoo platform was compared with the description on the field forms. Thus, if inconsistencies were identified, the plot data were returned to the field team for correction before the plot could be approved.

Twenty-six people (field and office staff) participated in the implementation of the NFI. Of these staff, only four were women, equivalent to 15.4 percent of the participating staff.

14.8 OTHER RELEVANT VARIABLES COLLECTED

Although for the purposes of this publication the forest variables (volume and biomass) were presented, it should be noted that the 2018 NFI was broader and included variables related to carbon and diversity (regeneration, biodiversity and phytosanitary status).

The shade-grown coffee stratum, although not a forest, is economically, socially and environmentally important for the country, covering 8.29 percent of the national territory; in this stratum, the same variables of the forest were measured, but with a positive difference when quantifying coffee trees with all their variables.

14.9 FUTURE PROSPECTS

It is expected that the Government of El Salvador, through its relevant institutions, will resume the planning process to update the next national forest inventory. To this end, the following actions are proposed:

- Add two additional strata to the four already considered:
  - trees outside the forest, that is, those trees located on land used for agriculture and livestock farming (pasture);
  - forest plantations, through a national inventory of forest plantations, given that in satellite images they are difficult to identify and separate from other forest strata and/or tree formations.
- Make relevant adjustments to the NFI design, without losing the methodological (comparative) relationship of a national forest inventory, which is based on a selection of permanent plots within and outside of forests. This selection should be made based on the systematic grid (21 103 plots) that is currently being used to determine the dynamics of land use and land cover, including forest.
- Institutionalise the national forest inventory, in the sense that government institutions should take on the role of updating the national forest inventory.
- Create mechanisms to improve the quality of field data collection processes.
- Implement field data collection technology using digital forms rather than paper forms.

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NEXT CHAPTER

GUATEMALA

Chapter 15

GUATEMALA

NATIONAL FOREST INVENTORY OF GUATEMALA

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15.1 HISTORICAL OVERVIEW OF NATIONAL FOREST INVENTORIES IN GUATEMALA

Guatemala is a country in Central America. Its Náhuatl name is Quauhtlemallan, which means "place of many trees" and it has a wealth of flora and fauna. The forest types that are classified in the country for estimation purposes are broadleaved forest, mixed forest, coniferous forest, mangrove forest and dry forest (Ramírez and Rodas, 2004; Aguilar, 2005; MAGA, 2015).

Guatemala has made multiple efforts to understand the current state of forests at the national level. In the 1960s, a forest inventory of the department of Petén was carried out by the Petén Economic Development and Promotion Project (Empresa Nacional de Fomento y Desarrollo Económico del Petén – FYDEP, according to its acronym in Spanish), the Food and Agriculture Organization of the United Nations (FAO) and the United Nations Development Programme (UNDP) (Guatemala, 1969). In the 1990s, a new forest inventory was conducted in Petén by the General Secretariat of Planning and Programming of the Presidency of the Republic (Secretaría General de Planificación y Programación de la Presidencia de la República). Between 2009 and 2010, the National Council for Protected Areas (Consejo Nacional de Áreas – CONAP, according to by its acronym in Spanish), conducted an inventory of cedar (*Cedrela odorata*), mahogany (*Swietenia macrophylla*) and rosul (*Dalbergia* spp.), all of which were listed under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (NPV, 2010).

Maps of forest cover began to be drawn up in 1998, and from 1991 onwards maps of forest cover dynamics were developed drawn up, specifically during the years 1991, 1996 and 2001 (UVG *et al.*, 2006), 2001–2006 (Castellanos *et al.*, 2011), 2006–2010 (INAB *et al.*, 2012), and 2010–2016 (INAB *et al.*, 2019). All these processes were carried out by government institutions and academic institutions. Details on the development of each of the maps can be found on the website of the Forest Information System of Guatemala (http://www.sifgua.org.gt/SIFGUAData/PaginasEstadisticas/Recursos-forestales/Cobertura.aspx).

The first National Forest Inventory (NFI) of Guatemala was carried out between 2002 and 2003 through a joint initiative between the National Forest Institute (Instituto Nacional de Bosques – INAB, according to by its acronym in Spanish) and the Forestry Action Plan for Guatemala (Plan de Acción Forestal para Guatemala) with the support of FAO. The objective was to collect information on forests and trees outside the forests for decision-making and monitoring of the forest sector policies. The sampling design of the first NFI was systematic and stratified and recording data from 108 sampling units (SUs).

Information was produced on the extent of forest lands by forest type, the productive potential of forests and trees outside forests, the condition and management of forests, and the uses of products and services that benefit forest-dependent communities (Ramirez and Rodas, 2004).

Since 2020, INAB and CONAP have been implementing the second NFI. The main objective is to determine the state of forests and trees outside forests at the national level, through a comprehensive and multipurpose assessment that is replicable and provides strategic information to the country. The sampling design is systematic with unaligned sampling selection proportional to the territory. Information from 715 SUs being recorded (INAB and CONAP, 2020). Table 15.1 presents the characteristics of the two cycles of the NFI in Guatemala.

The information collected in both inventories reports on the growing stock, timber quality, biomass and forest carbon, forest structure, forest composition, state of forest fuel materials, state of health, current management, information on the villages or participating communities, and the productive potential of goods and services (INAB and CONAP, 2020).

15.2 TERMS AND DEFINITIONS OF THE NATIONAL FOREST INVENTORY OF GUATEMALA

The Guatemalan Forestry Law (Decree No. 101-96) defines forest as "the ecosystem where trees are the dominant and permanent plant species" (Guatemala, 1996). As this definition is not very practical for field measurements, the first NFI in Guatemala used a definition based on the Global Forest Resources Assessment (FRA) from the year 2000 (FAO, 1998): "forest land or land that is not in use spanning more than 0.5 hectares with trees higher than 5 m and a canopy cover of more than 10 percent" (FAO, 1998).

The term specifically excludes tree formations used in agricultural production systems, such as fruit plantations and agroforestry systems, as well as trees growing in urban parks and gardens (FAO, 1998; Ramirez and Rodas, 2004). During the first NFI (2002–2003), the FRA definitions of other wooded land and other land were used, and the terms total volume, commercial volume and above-ground biomass were defined, as described in the results report (Ramirez and Rodas, 2004).

After the first NFI, the national definition of forest was discussed and agreed by the Interinstitutional Monitoring Group on Forests and Land Use (Grupo Interinstitucional de Monitoreo de Bosques y Uso de la Tierra – GIMBUT, according to its acronym in Spanish) as follows: land area covered by trees with a minimum canopy cover of 30 percent that forms a continuous mass of at least 0.54 ha, with a minimum width of 60 metres (m). The term includes forest plantations, rubber (*Hevea brasilensis* [Willd. ex A. Juss.]), secondary forests and semi-seasonally dry forests (INAB and CONAP, 2020; INAB *et al.*, 2012).

This definition has been used for the reference level of emissions presented to the Emissions Reduction Programme of the Forest Carbon Partnership Facility Carbon Fund (Government of Guatemala, 2019) and it is the definition used in the second National Forest Inventory (INAB and CONAP, 2020).

A definition of trees outside forests was also established given the importance of knowing the state of trees in all land use classes. The term is defined in Resolution No. JD.02.12.2016 (Regulation of the PROBOSQUE Law) as follows:

> *scattered trees in a given area, where there is no defined horizontal structure, no natural regeneration, no successional state of the forest, with a basal area not exceeding four (4) square metres per hectare; these trees are not considered as forest of any kind (Resolution No. JD.02.12.2016, 2016, Art. 5).*

TABLE 15.1

Sampling designs of the two national forest inventories of Guatemala

Inventory cycle	Implementation period	Scale	Sampling design	Number of sampling units
First NFI	2002–2003	National	Stratified systematic	108
Second NFI	2021–2022	National	Systematic unaligned	715

Source: Prepared by the authors.

Subsequently, in the methodological framework of the second NFI, trees outside forests are defined as follows:

> *tree formations located in areas not considered as forest, spanning more than 0.54 ha with a minimum width of 30 m and a canopy between 10 percent and 30 percent. The term includes tree formations in agroforestry and silvopastoral system arrangements (INAB and CONAP, 2020, p. 25).*

Another important definition to operationalise the definition of forest is the term "tree," which is defined as a woody plant with a stem and defined crown, with secondary growth that at its maturity stage reaches a minimum height of 5 m and a minimum diameter at breast height of 10 centimetres (cm) (INAB and CONAP, 2020; INAB *et al.*, 2012).

The definition of forest developed by GIMBUT is used in the country reports to FRA, given that the maps of forest cover dynamics have been used as data sources for these reports (Guatemala, 2019). However, some operational difficulties have recently been detected in the 2016 forest cover map (Duarte *et al.*, 2019). For this reason, work has been done recently to harmonize criteria and thresholds among GIMBUT institutions to improve the application of the definitions of forest, other classes of vegetation, and other land use classes (Saput *et al.*, forthcoming).

TABLE 15.2

Summary of definitions used to implement the National Forest Inventory in Guatemala

Term	Definition	Variables and thresholds
Forest	First National Forest Inventory (NFI), 2002–2003 Forest land spanning more than 0.5 hectares, with trees reaching a height of 5 metres and 10% canopy cover. Trees in agriculture, agroforestry, parks and urban gardens are not included.	Minimum area: 0.5 ha Canopy cover: 10% Tree height: 5 m Minimum width: not defined Exceptions: agroforestry and trees in urban parks and gardens
	Second NFI, 2021–2022 A land area covered with trees with a minimum canopy cover of 30%, forming a continuous mass of at least 0.5 hectares with a minimum width of 60 metres. The term includes forest plantations, secondary forests and semi-seasonally dry forest	Minimum area: 0.5 ha Minimum width: 60 m Canopy cover: 30% Tree height: 5 m Exceptions: not defined Includes: Forest plantations, secondary forests and dry forests
Other wooded land	First NFI, 2002–2003 Non-forest land spanning more than 0.5 ha with trees capable of reaching a height of 5 m and canopy cover between 5% and 10%	Minimum area: 0.5 ha Tree height: 5 m Canopy: 5% to 10% Exclusions: not defined
Other land	First NFI, 2002–2003 Land not classified as forest or other wooded land, including agricultural land, natural grassland without trees, pastures, and land with buildings	Minimum area: not defined Canopy: not defined Exclusions: forest or other wooded land
Volume	First NFI 2002–2003 Total growing stock: volume over bark of all living trees with diameter at breast height (DBH) greater than 20 cm from the base to the total reported height. Branches excluded, bark included. Growing stock with commercial potential: volume over bark of reported species with commercial potential for trees with DBH greater than 20 cm from the base to the reported commercial height	Total and commercial growing stock: DBH minimum: 20 cm Total height: from the base to the last branch height Bark not included Commercial height: not defined Species considered for total stock: all living trees Species with commercial potential: living trees of species with an established market and for domestic construction
Biomass and carbon	First NFI 2002–2003 Above-ground biomass: above-ground biomass of trees greater than 10 cm DBH	Minimum DBH: 10 cm

Source: **Ramírez, C. & Rodas, R.** 2003. *Inventario Nacional Forestal: Manual de Campo.* Forest Resources Assessment Programme. Guatemala City, FAO.; **INAB (National Forest Institute)& CONAP (National Council for Protected Areas).** 2020. *Marco metodológico para el segundo ciclo del Inventario Nacional Forestal de Guatemala.* Guatemala City.

Table 15.2 presents the definitions of forest from the first and second cycle of the NFI in Guatemala. In addition, the definitions of other wooded land, other land, volume and biomass used by the NFI 2002–2003 are presented.

The latter definitions have not been discussed yet for the NFI 2021–2022.

15.3 SAMPLING DESIGN

15.3.1 FIRST NATIONAL FOREST INVENTORY OF GUATEMALA

The sampling design was systematically stratified with a distribution of 108 sampling units (SUs) over the country's entire land area with a different intensity in each stratum. The strata divided the country into three regions (north, centre and south) and were built based on natural divisions according to physiographic, edaphic and climatic parameters (Figure 15.1) (Ramírez and Rodas, 2004).

15.3.2 SECOND NATIONAL FOREST INVENTORY OF GUATEMALA

The design of the second NFI was adjusted based on information and experiences from the first inventory. The new systematic unaligned design features a proportional allocation of the sample over the entire national territory. The sample selection was done on a grid measuring 12.4 kilometres (km) by 12.4 km. Within each grid cell, a point was randomly selected where the SU was located (Figure 15.2) (INAB and CONAP, 2020).

The size of the sample was determined based on data from the first NFI cycle, which were also used to establish the coefficients of variation for three main variables: basal area, volume and biomass. These coefficients were then combined with cost data, resulting in an optimal design with respect to the size, number and distance between SUs and plots. Thus, for the second cycle of the national forest inventory, 715 SUs were selected, with an expected sampling error close to 11 percent, at 95 percent confidence (INAB and CONAP, 2020).

The inventory is designed to provide data at country level. However, there may be interest in collecting data at a smaller scale, for instance, at regional, departmental, or municipal level, or for protected areas or specific ecosystems (mangrove, dry forest, wetlands, etc.). For this reason, the NFI sampling grid was intensified 4, 16 and 64 times, resulting in the intensification levels provided in Table 15.3.

TABLE 15.3

Intensification levels of the National Forest Inventory sampling grids to generate small-scale data

Intensification level	Grid size (square kilometres)	Number of sampling units
1	12.4	715
2	6.2	2 860
3	3.1	11 369
4	1.55	45 426

Source: **INAB & CONAP.** 2020. *Marco metodológico para el segundo ciclo del Inventario Nacional Forestal de Guatemala.* Guatemala City.

Table 15.4 shows a summary of the number of samples from the two NFIs in Guatemala, as well as the distribution of SUs within and outside of forests, according to the definitions used in each case.

TABLE 15.4

Distribution of sampling units in the two national forest inventories in Guatemala

Name	Total land area (1 000 ha)	Number of sampling units			Total
		Forest	Other wooded land	Other land	
First NFI, 2002–2003	10 889	39.6	17.9	45.4	108 [1]
Second NFI, 2021–2022	10 889	231	484 [2]		715

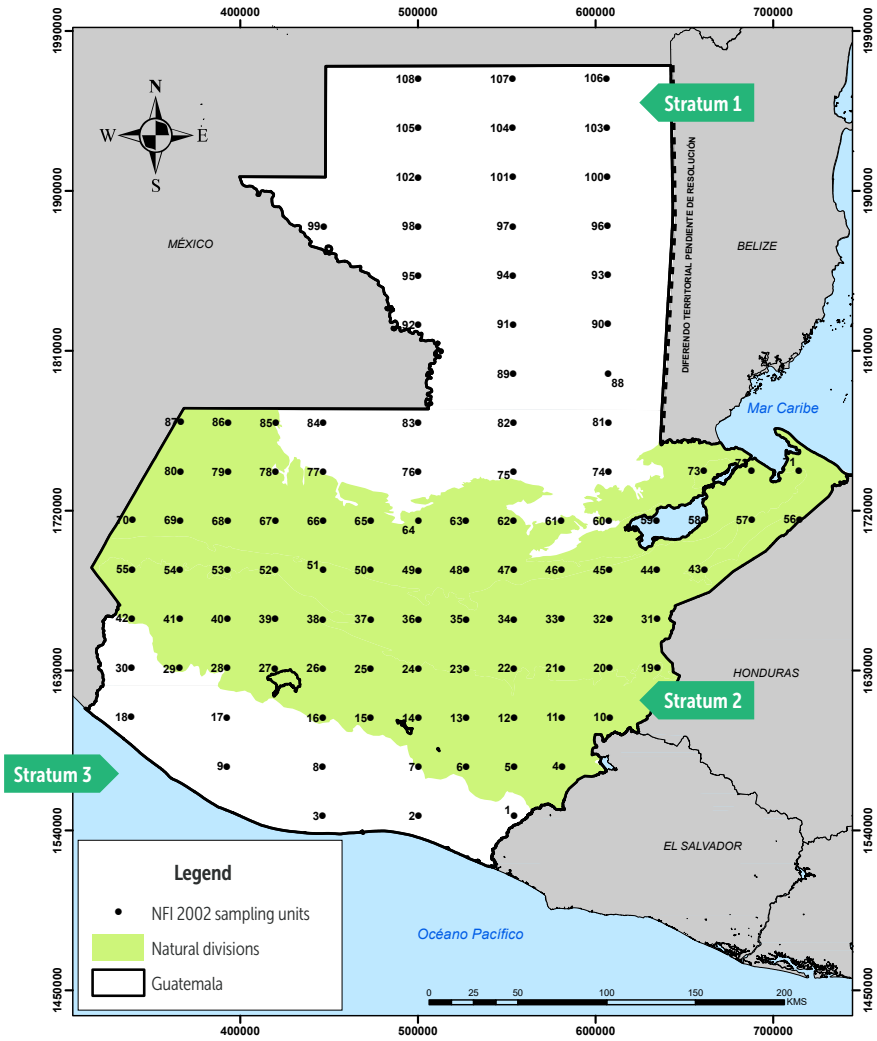
Note: [1] Of which 2.8 sampling units were unknown and 2.4 corresponded to inland water.

[2] This amount corresponds to plots that are not defined as "forest"; however, it is not yet known whether they belong to "other wooded land" or "other land" because the second NFI is currently being implemented.

Source: **Ramírez, C. & Rodas, R.** 2003. *Inventario Nacional Forestal: Manual de Campo.* Forest Resources Assessment Programme. Guatemala City, FAO.; **INAB & CONAP.** 2020. *Marco metodológico para el segundo ciclo del Inventario Nacional Forestal de Guatemala.* Guatemala City.

FIGURE 15.1

Sampling design of the 2002–2003 National Forest Inventory of Guatemala



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Note: Stratum 1: north; Stratum 2: centre; Stratum 3: south.
Source: **Ramírez, C. & Rodas, R.** 2004. *Evaluación Nacional Forestal. Inventario Forestal Nacional 2002-2003: Guatemala.* Working Paper No. 92. Rome, FAO.

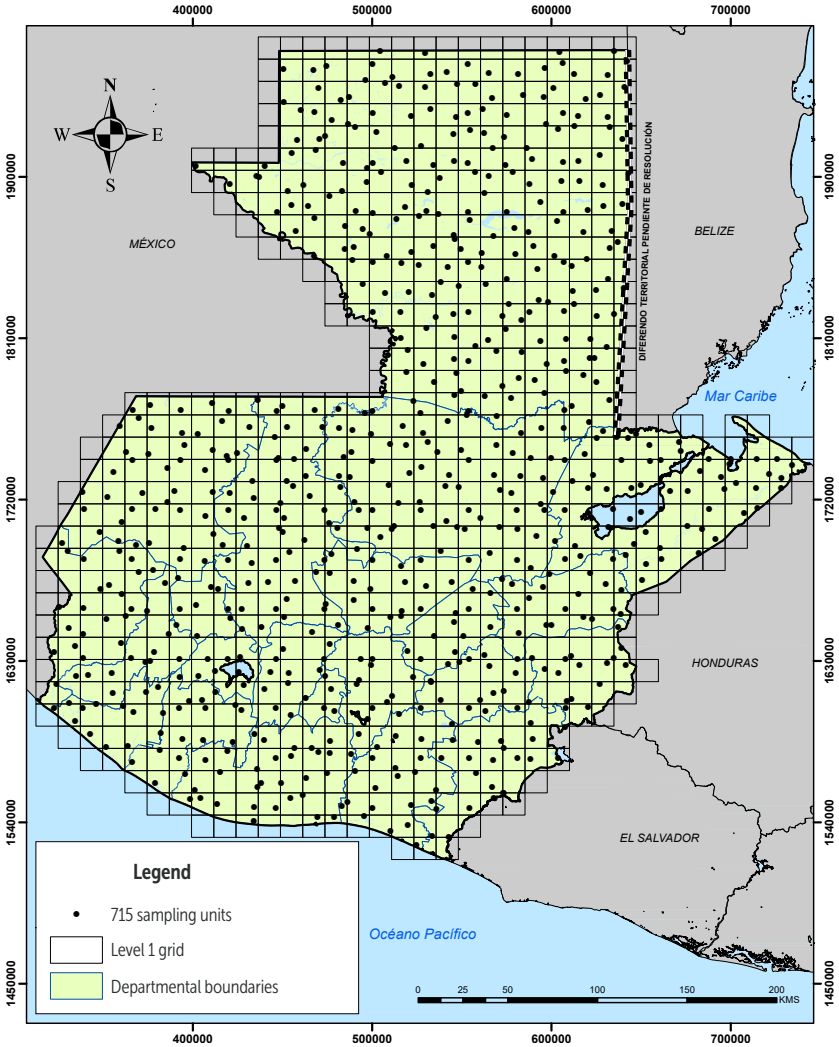
15.4 SAMPLING UNIT DESIGN

15.4.1 FIRST NATIONAL FOREST INVENTORY OF GUATEMALA

The SU design of the first NFI (2002–2003) is shown in Figure 15.3. Each SU had a total area of 2 ha, distributed in four rectangular plots measuring 250 m by 20 m (0.5 ha). The variables were measured using different dimensions of nested subplots configured within the main plot. The following information was collected: land area by forest type, land area by tenure system and land use designation, growing stock in forests and trees outside forests, state and health of forests, stock of three non-wood forest products (xate, bayal and osier), and information on the use of forest products and services; the latter was collected through socioeconomic interviews (Ramírez and Rodas, 2003).

FIGURE 15.2

Distribution and spatial location of the sampling units of the second cycle of the National Forest Inventory of Guatemala



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Source: **INAB & CONAP.** 2020. *Marco metodológico para el segundo ciclo del Inventario Nacional Forestal de Guatemala.* Guatemala City.

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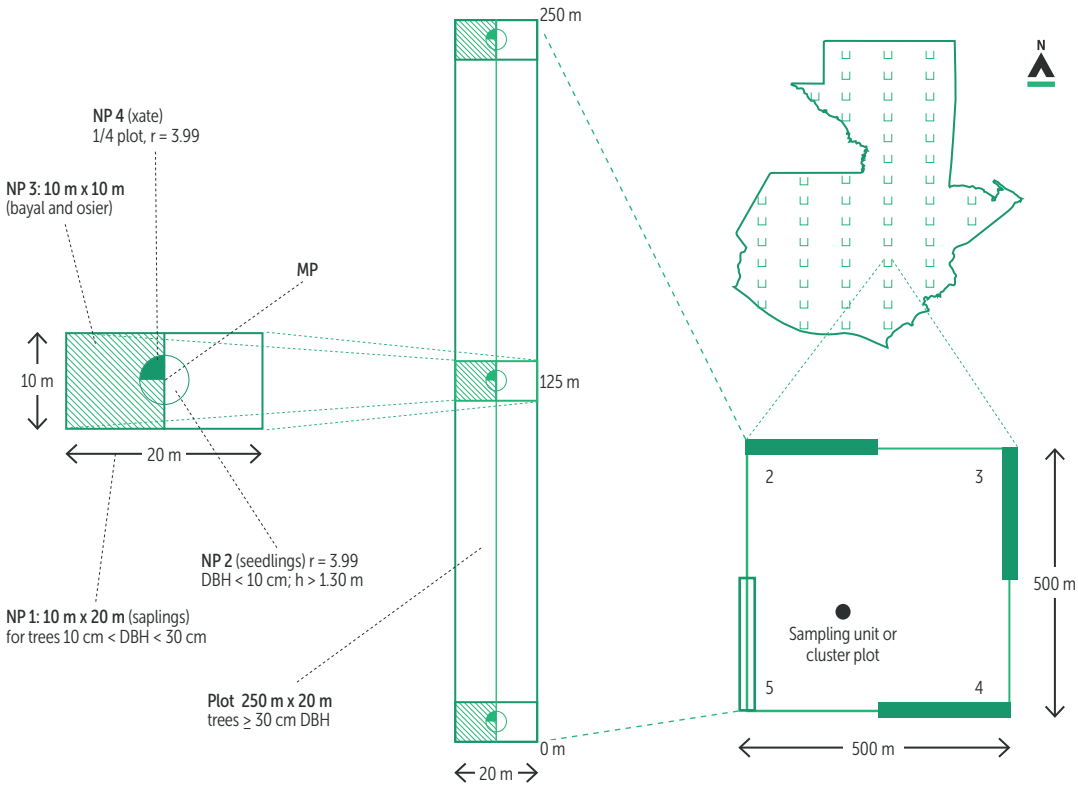
FIGURE 15.3

Sampling unit design of the first National Forest Inventory (2002–2003)



Notes: DBH: diameter at breast height; MP: measurement point; NP: nested plot.
Source: **Ramírez, C. & Rodas, R.** 2003. *Inventario Nacional Forestal: Manual de Campo.* Forest Resources Assessment Programme. Guatemala City, FAO.

15.4.2 SECOND NATIONAL FOREST INVENTORY OF GUATEMALA

The SU of the second inventory consists of three circular plots, aligned from south to north (Figure 15.4). Each plot is 30 m in diameter, separated by 10 m between the edge of each plot and 40 m between the centre of each plot. The sampling units cover a total area of 2 120.58 square metres (m²) (INAB and CONAP, 2020). The change in SU size was part of the cost and variability analysis which considered two main criteria. The first was an administrative aspect: to facilitate the NFI institutionalization process, it was decided that the field survey should take an average of 8 hours per day, including transport. Second, circular plots were chosen given the relative ease and quality of remeasurements, since only one central reference point is needed for each plot; by contrast, rectangular plots depend on angular variations in the measurements of the line that must be drawn to locate trees.

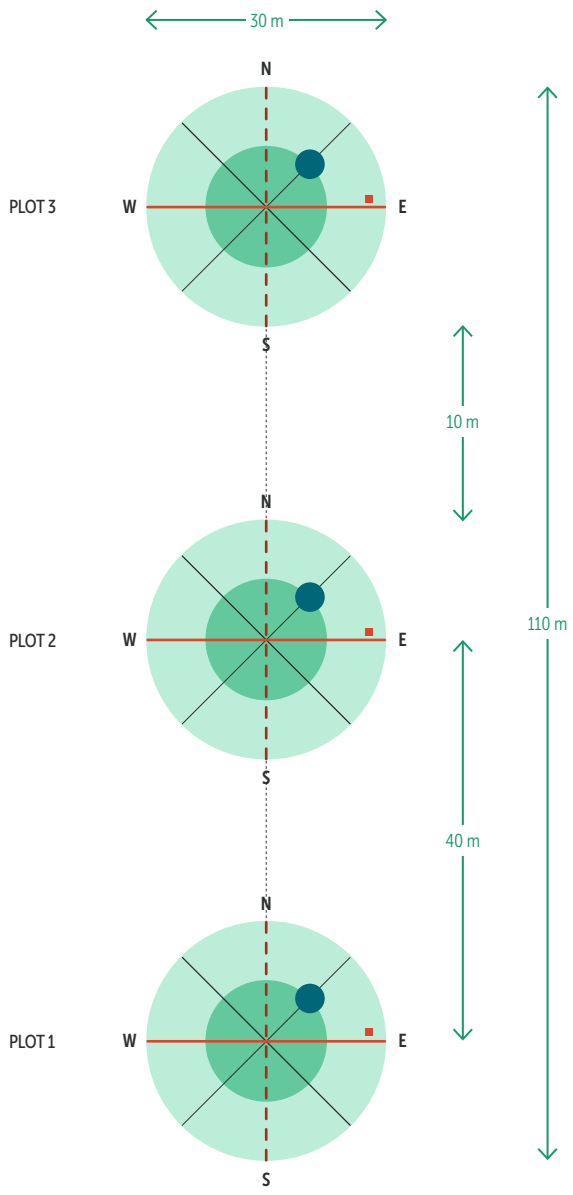
The plots are circular and nested in order to assess different components: trees (different diameters), regeneration, non-wood forest products, dead wood, litter, soil and site characteristics. Figure 15.5 shows the layout of each plot and Table 15.5 shows the dimensions of each section of the plot according to the size of the elements to be measured (INAB and CONAP, 2020).

15.5 LAND AREA, VOLUME AND BIOMASS CALCULATION

The country's forest land area has been estimated through forest cover maps made in 1991, 1996 and 2001 (UVG *et al.*, 2006), 2006 (Castellanos *et al.*, 2011), 2010 and 2016 (INAB *et al.*, 2019) using Landsat images. In the first NFI cycle (2002–2003), forest area, forest types (broadleaved, coniferous,

FIGURE 15.4

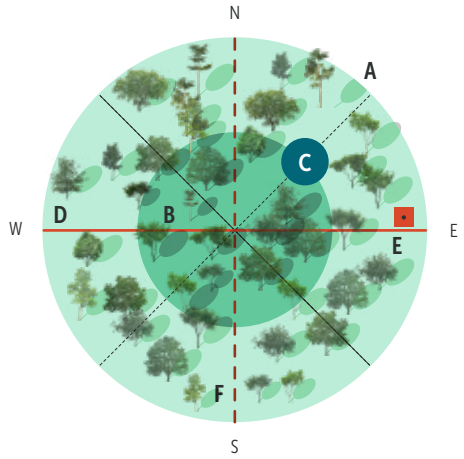
Design of the sampling unit used to collect the National Forest Inventory data



Source: **INAB & CONAP.** 2020. *Marco metodológico para el segundo ciclo del Inventario Nacional Forestal de Guatemala.* Guatemala City.

FIGURE 15.5

Design of plot used to collect National Forest Inventory data



Source: **INAB & CONAP.** 2020. *Marco metodológico para el segundo ciclo del Inventario Nacional Forestal de Guatemala.* Guatemala City.

TABLE 15.5

Configuration of plot according to elements of measurement

Section	Dimensions	Measurement elements
A	r = 15 m (707 m^2)	Trees ≥ 20 cm DBH and stumps
B	r = 10 m (314 m^2)	Trees 10 cm to 19.9 cm DBH and non-wood forest products
C	r = 3 m (28 m^2)	Trees ≤ 9.9 cm in diameter
D	30 m	Lying dead wood LDW: ≥ 5 cm in diameter
E	0.25 m^2	Leaf litter and soil
F	30 m	Forest structure (south–north)

Notes: DBH: diameter at breast height; LDW: lying dead wood; r: radius.
Source: Source: **INAB & CONAP.** 2020. *Marco metodológico para el segundo ciclo del Inventario Nacional Forestal de Guatemala.* Guatemala City.

mixed and mangrove) and other land uses were also estimated based on data collected in the SUs (Ramirez and Rhodes, 2004). Ratio estimators were used in area calculations (Cochran, 1977).

The equations developed by Peters (1977) for conifer species were used to calculate volume during the first NFI cycle (2002–2003). For broadleaved species, a general formula was used that had been developed in Quintana Roo, Mexico by the General Directorate of National Forest Inventory and is cited in INAB's *Forestry Technical Manual* (1999). Due to limitations of the aforementioned formulas for diameters at breast height (DBH) greater than 90 cm, the general formula of the cylinder multiplied by a 65 percent form factor was used (Ramírez and Rodas, 2004).

The above-ground biomass was estimated using Brown's equations (1997), as there were no allometric biomass equations available for the country.

Variable estimation protocols are being developed for the second NFI, which will consider the procedures of the first cycle to conduct comparative statistics. Given that each cycle has a different SU design, change estimates will have certain constraints.

The equations used in the first NFI are described in Table 15.6.

15.6 RESULTS OF THE FIRST NATIONAL FOREST INVENTORY, 2002–2003

Only the results of the first NFI are presented (Table 15.7), as the second NFI is still in the field survey phase. The forest area estimated with the data from the first NFI cycle was 4 046 015 ha, which corresponds to 37.2 percent of the national territory.

TABLE 15.6

Equations used for volume and biomass calculations

Variables	Equation	Reference
Total volume (m^3)	*Cupresus lusitanica* $V = 0.013451922 + 0.0000289134\ DBH^2\ H$	(INAB, 1999)
	Pinus ayacahuite $V = 0.0197725259 + 0.0000288708\ DBH^2\ H$	
	Pinus caribaea $V = 0.0684728026 + 0.0000309465\ DBH^2\ H$	
	Pinus montezumae $V = 0.0229946375 + 0.0000277515\ DBH^2\ H$	
	Pinus oocarpa $V = 0.0268287659 + 0.0000287215\ DBH^2\ H$	
	Pinus pseudostrobus $V = 0.0050811768 + 0.0000286052\ DBH^2\ H$	
	Pinus rudis $V = 0.0179835819 + 0.0000283104\ DBH^2\ H$	
	Broadleaved species $V = 0.0197725259 + 0.0000288708\ DBH^2\ H$	
	Trees with DBH greater than 90 cm $V = Basal\ area \times H \times 0.65\ (form\ factor)$	
	Where: *DBH:* diameter at breast height *H:* height *V:* volume	
Biomass (t)	Coniferous species $Y = Exp\ (-1.170 + 2.119 \times Ln\ DBH)$	Brown (1997)
	Broadleaved species $Y = 42.69 - 12.8\ (DBH) + 1.242\ (DBH^2)$	
	Where: *DBH:* diameter at breast height *Y:* biomass	

Source: **INAB** 1999. *Manual Técnico Forestal.* Guatemala City.; **Brown, S.** 1997. *Estimating biomass and biomass change of tropical forest: A primer.* FAO Forestry Paper 134. Rome, FAO.

The forests were divided into 82 percent broadleaved, 10 percent coniferous and 8 percent mixed forests. Mangrove forests were counted in the broadleaved category and forest plantations accounted for less than 1 percent. With regard to land tenure, forests were estimated to be 38 percent private, 34 percent national public, 8 percent municipal public, 15 percent communal and 5 percent undetermined (Ramírez and Rodas, 2004).

15.7 OTHER RELEVANT VARIABLES

During the first NFI, statistics were also provided on the potential volume of timber products, the potential of three non-wood forest products (xate [*Chamaedorea* sp.], bayal [*Desmoncus ferox* Bartlett] and osier [*Monstera pertusa* (L.) de Vriese]), the potential volume of firewood and the use of forest species.

The potential of timber products was calculated for all identified conifer species. Broadleaved species were selected according to market development: fully developed markets, potentially developed markets and species with commercial potential.

The estimation of firewood is of great importance for Guatemala, as it is very valuable in the rural economy. In non-forest areas it is a resource that could be better managed to provide fuel for rural communities and decrease pressure on forests. Commercially valuable broadleaved species were also selected for forest concessions in the Maya Biosphere Reserve, located in the northern stratum (Ramírez and Rodas, 2004).

The potential of forests to provide non-wood forest products was demonstrated, attesting to their importance in the development of management strategies that aim to conserve natural resources while also sustaining and promoting the livelihoods of people who depend on them.

TABLE 15.7

Results of the first National Forest Inventory, 2002–2003

Variable	Results		Description
Land area (1 000 ha)	Forest	4 046.02 (18%)	Total forest land area (% sampling error)
	Broadleaved	*3 336.44 (22%)*	Forest land area per forest type (% sampling error)
	Coniferous	*396.94 (46%)*	
	Mixed	*312.64 (46%)*	
	National public	1 367.73 (34%)	Forest land area per land tenure type (% sampling error)
	Municipal public	341.75 (96%)	
	Communal	592.88 (59%)	
	Private	1 531.13 (30%)	
	Undetermined	212.52 (143%)	
	Inside protected areas	1 643.14 (44%)	Forest land area per protection status (% sampling error)
	Outside protected areas	2 402.88 (26%)	
Volume (m^3/ha)	Forest	141.3 (20%)	Total average volume per hectare for trees recorded with diameter at breast height (DBH) greater than 10 cm (% sampling error)
	Broadleaved	*143.2 (22%)*	
	Coniferous	*98.9 (40%)*	
	Mixed	*77.1 (37%)*	
Biomass (t/ha)	Forest	124.0 (17%)	Average above-ground biomass in tonnes per hectare for trees recorded with DBH greater than 10 cm (% sampling error)
	Broadleaved	*123.5 (19%)*	
	Coniferous	*88.5 (32%)*	
	Mixed	*87.5 (31%)*	

Source: **Ramírez, C. & Rodas, R.** 2004. *Evaluación Nacional Forestal. Inventario Forestal Nacional 2002-2003: Guatemala.* Working Paper No. 92. Rome, FAO.

The information collected was disaggregated by gender and youth for products such as commercial timber, firewood, timber for construction, hunting of wild animals and plant food harvesting (Ramírez and Rodas, 2004).

Other relevant information that was collected included the characterization of forests according to their origin, composition, horizontal and vertical structure, function, type and purpose of timber product harvesting, harvesting technology, disturbances, phytosanitary condition, environmental problems and intensity of land use (Ramírez and Rodas, 2004).

In addition, the communities near the SUs were described according to ethnic groups, productive activities and migratory dynamics. An analysis of the use of forest products and services was also carried out, prioritising products such as timber, firewood, construction materials, wild animals and plant foods. These were described according to their intended use, supply and demand, harvesting frequency, type of worker disaggregated by gender and age (adults/children), type of transport for harvesting, and land use rights and conflicts (Ramírez and Rodas, 2004).

All the aforementioned variables are also assessed in the second NFI. However, there are variations; for instance, for dry forest ecosystems, trees from 5 cm DBH must be measured, due to the fact that their growth in diameter is less than for coniferous and broadleaved forests. Other relevant variables recorded in the second NFI are soil organic carbon, lying dead wood and leaf litter, which will be used to complete the statistics on forest carbon stocks in the country.

15.8 IMPLEMENTATION AND QUALITY CONTROL OF THE FIRST NATIONAL FOREST INVENTORY, 2002–2003

The first NFI received technical and financial support from FAO. An interinstitutional Steering Committee was formed by INAB, CONAP, the Universidad del Valle de Guatemala (UVG), the School of Agronomy of the Universidad de San Carlos de Guatemala, and FAO to oversee its implementation. A technical unit was hired to coordinate the implementation of the field survey, which was organized into six operational regions that were selected based on administrative, topographical and socioeconomic conditions. In each operational region, a company or team of independent consultants was hired on condition that it demonstrated experience in forest inventories, operational capacity and knowledge of the region. The selection of the companies was made by the Steering Committee (Ramírez and Rodas, 2004).

In order to obtain the highest quality data, the INAB and CONAP field crews and technical supervisors were trained on the NFI methodology and the procedures for data planning and collection that are described in the NFI field manual (Ramírez and Rodas, 2003). The training included practical exercises on the use of measuring instruments, location and permanent marking of plots and trees without physical evidence, classification of forest types and land uses, measurement of trees and other site elements, qualitative observations, completion of forms, permit application techniques, and implementation of socioeconomic interviews and inputs to the database (Ramírez and Rodas, 2003).

Field crews prepared reports for each SU describing access to the SU, contact with landowners, establishment of the permanent markings, description of land uses, and constraints to data collection. These reports were attached to the field forms, botanical samples, database and photographs.

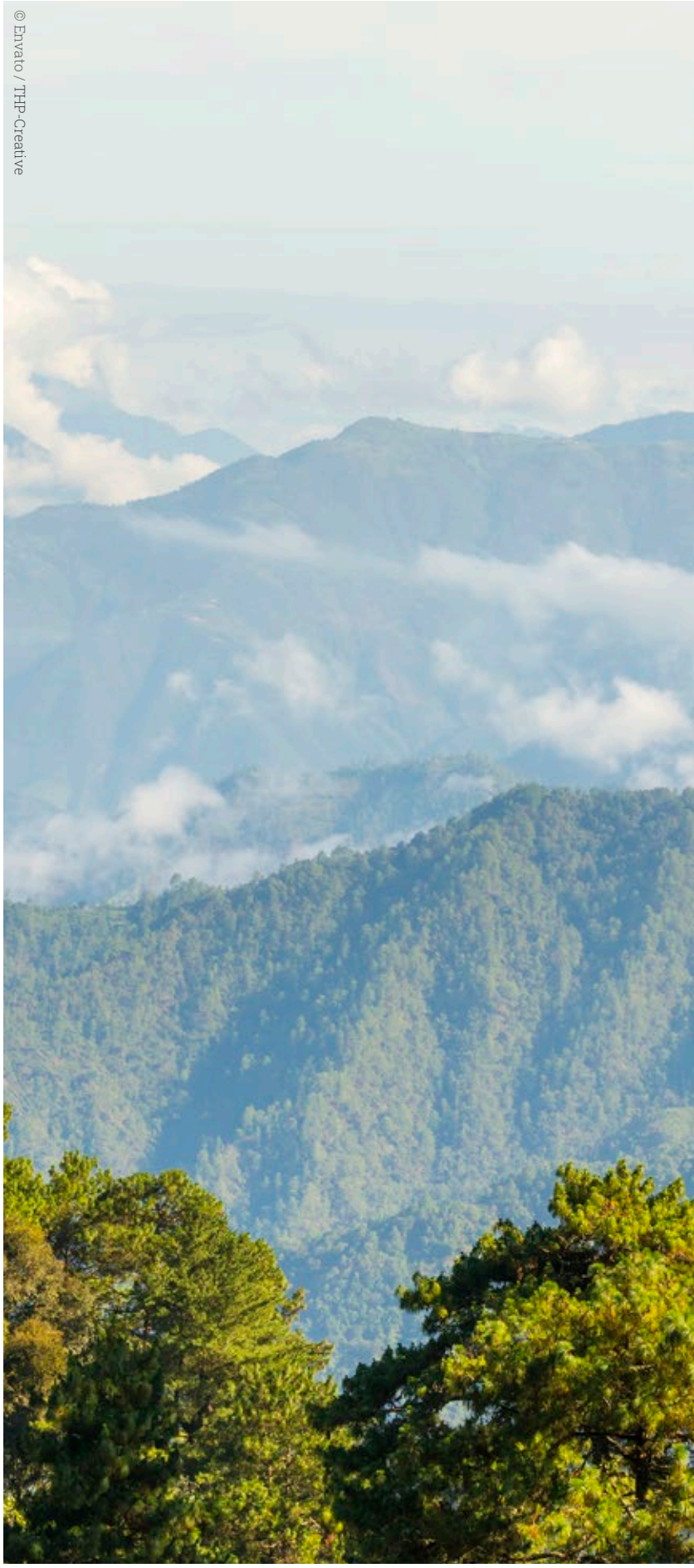
The technical unit supervisors participated in each crew's first SU survey in order to address any doubts about the methodology and classification of forest types, and to observe the correct execution, measurement and recording of data in the forms. The field crews had to submit a detailed data collection plan and the technical unit provided assistance with permit applications, technical questions and any problems that limited the proper implementation of the field survey. With the support of several regional technicians from forest administration institutions and municipalities, data collection was supervised and supported in 28 SUs (26 percent of the total of 108 SUs). As a means of monitoring and evaluating measurements, 9 SUs were remeasured; this also made it possible to gain experience in locating the plots using the information provided in the field reports. After half of the field surveys had been conducted, a meeting was held with all the field crews to share experiences, best practices, technical queries and opportunities for improvement. All SUs went through different screening checks, including the location of the permanent markings, review of reports, direct field supervision, review of reported species, and review of the database in relation to the

paper forms, until they were approved for inclusion in the final database. This was followed by data cleaning procedures and technical meetings to make decisions on the management of discrepancies in the data, which were documented in an analysis log.

Regarding the second NFI, steps have been taken towards the institutionalization of field measurements; INAB and CONAP now act as lead agencies for forestry activities outside of and within protected areas, respectively, and jointly coordinate the implementation of the field phase. More specifically, INAB has included this process as part of its annual operational plan for 2021 and, drawing on the experience of the two inventories, it is working to create a mechanism to enable both institutions to include the updating of data and measurement variables in their annual strategic and operational planning framework, as well as in their budget implementation.

Both the implementation and institutionalization processes have differed between the first and second NFI, as the involvement of INAB and CONAP has materialised through specific activities. In the case of INAB, improvements have been made in operational institutional planning and it is hoped that these can also be included in strategic and five-year planning. In addition, both institutions have assumed responsibility for conducting the field measurements with in-house staff as the main implementation mechanism. One of the main next steps is to finalise the institutionalization strategy to guide the actions of each institution, in order to have clear technical and strategic guidelines to conduct a third inventory.

A Steering Committee was also set up for the implementation of the second NFI, led by INAB and CONAP. The Committee was divided into subcommittees to address specific issues such as training, management and external cooperation, communication, and data storage and analysis. Each subcommittee works in parallel and in coordination to guide the inventory implementation or field phase. The implementation is being developed through two mechanisms: the first mechanism uses internal staff from both institutions who are directly responsible for establishing the SUs, which guarantees an active participation of technical staff in all regions; the second mechanism is through external cooperation agencies, which hire consultants to establish the SUs. In the second case, the institutional role is to provide all the necessary information for the location of the areas, support, and advice for the correct application of the methodology.



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Strategic alliances with local authorities, second-tier community organizations, and academia have also been of vital importance for the implementation of the NFI, since the multipurpose objective will generate information of interest to all actors in the forestry sector. Their participation in the data collection process is thus crucial to obtaining the first results during the year 2022.

In this second inventory, 715 SUs are expected to be established, taking into account that they will measure forest and other land use areas with tree cover, as it is intended to monitor the behaviour of current land use in the future.

For data quality control, staff is being trained and there is also a crew with highly skilled staff at national level. There are plans to implement three controls: *ex ante*, which consists of supporting the establishment of the first SU; *ex post*, through a corroboration of recorded data; and an internal audit, through the comparison of data gathered independently, that is, establishing SUs with the quality control crew in order to subsequently assess them.

15.9 FUTURE PROSPECTS

By completing the second NFI in Guatemala, it is expected, among other things, to update and compare the stocks of commercial and non-commercial timber, firewood and some non-wood forest products in forests and trees outside forests; growth and mortality dynamics; floristic composition; forest regeneration capacity; species distribution; forest density and its variation over time; degree and type of forest management; carbon content stored in biomass in different carbon pools. It is also expected to update data on socioeconomic aspects in order to carry out an analysis on the social dynamics of forest resource use.

Regarding the process of institutionalizing the NFI, it is expected to establish a continuous process of collection, analysis and reporting of information on the progress of the national public policy indicators concerning the forestry sector and the conservation of protected areas.

The second NFI will enable the country to better respond to its reporting commitments in the context of the incentive-based initiatives for reducing carbon dioxide emissions under the Reducing Emissions from Deforestation and Forest Degradation (REDD+) mechanism, and to serve as the primary data source for the Greenhouse Gas Inventory (GHGI) and the progress report of national indicators regarding the National Forest Landscape Restoration Strategy.

Similarly, the information gathered is expected to contribute to compiling the Integrated Forest Account data series as part of the System of Integrated Environmental and Economic Accounting, an international analytical framework promoted by the United Nations system whose overall purpose is to analyse the reciprocal relationships between the economy and the environment. Within this system, the NFI will provide important information to better reflect the contribution of the forest sector to the national economy, based on data on stocks and the use of different forest products and by-products, assessed directly in the field.

Within the national context, it is expected that the updated information on the current state of forests and trees outside forests will create a link between the results of the strategies and policy instruments that have been developed over the past 15 years to promote sustainable forest management and the importance of continuously updating information for the forestry sector.

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Chapter

MARTINIQUE, GUADELOUPE AND FRENCH GUIANA

TOWARDS A NATIONAL FOREST INVENTORY IN FRENCH OVERSEAS TERRITORIES IN LATIN AMERICA AND THE CARIBBEAN: **MARTINIQUE, GUADELOUPE AND FRENCH GUIANA**

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16.1 HISTORICAL OVERVIEW OF FOREST INVENTORIES

The French National Forest Inventory (NFI) was established in 1958 and has provided estimates since 1960. For the five-year period between 2014 and 2018, the forest area and growing stock – with diameter at breast height (DBH) of 7.5 centimetres (cm) or more – amount to 16.8 million hectares (ha) and 2.8 billion cubic metres (m^3), respectively. However, these estimates only concern metropolitan France (mainland France and Corsica) and not the overseas territories.

In 2014, Law No. 2014-1170 added a new article to the existing forestry code. It states that the NFI "takes into account the particularities of woods and forests located in Guadeloupe, French Guiana, Martinique, Réunion, Mayotte, Saint Barthélemy, Saint-Martin and Saint Pierre and Miquelon" (Article L. 151-3, French Republic, 2014). Most of these territories are located in South America (French Guiana) and the Caribbean (Guadeloupe, Martinique, Saint Barthélemy and Saint-Martin).

French Guiana (4°13'N, 52°59'W) covers an area of approximately 8.2 million ha, in the eastern part of the Guiana Shield. The climate is equatorial, with annual rainfall ranging from 2 000 millimetres (mm) (south and west) to 4 000 mm in the north. The Amazon Forest covers more than 97 percent of the area and is almost continuous. The population density is very low (less than three persons per square kilometre) and the human settlements are mostly dispersed in the northern part of the territory and along the two main frontier rivers.

The Caribbean islands, however, are smaller. The climate is tropical with some contrasted seasons. Only the two biggest territories (Guadeloupe with 169 000 ha and Martinique with 106 000 ha) are considered in the present chapter.

Collectively, these territories account for more than one-third of all French forests. This is mainly owing to French Guiana, which has more than 8 million ha of forest and represents more than 97 percent of all overseas forests, according to the National Institute of Geographic and Forest Information (Institut National de l'Information Géographique et Forestière – IGN, according to its acronym in French) (IGN, 2018). However, even though it is stipulated by law, no forest inventory has been initiated yet in these territories. The main reason for this is the lack of dedicated human and financial resources. Nevertheless, although no proper inventory exists, partial or parallel attempts have been carried out to improve knowledge of forest resources and biodiversity (see Table 16.1 for a summary).

In the two Caribbean islands, the situation of forest monitoring is similar. The forest cover can only be deduced from maps produced at irregular intervals and is difficult to compare across time periods. The first land use maps of Guadeloupe and Martinique date back to 1950 and 1951, respectively (Guitet *et al.*, 2017). The last one was produced in 2019 from a 2017 aerial survey in Martinique (Figure 16.1) and is based on 10 cm resolution imagery. In Guadeloupe, a detailed map has not yet been produced and specific work has been carried out (IGN, 2018).

In French Guiana, several historical initiatives have been launched to assess forest resources. Because of the limited access to the interior of the territory, they first focused on the northern part of the country, which is subject to logging. Hence, between 1962 and 1970, the inventory known as "au millième" (to the thousandth) was carried out by the National Forests Office (Office National des Forêts – ONF, according to its acronym in French), along north–south transects of up to 145 km. Only trees of commercial species with DBH greater than 10 cm were measured and grouped into 27 species groups. This inventory is only partially digitised.

The second noteworthy initiative is the so-called "papetier" (papermaker) inventory financed by the paper industry and conducted by the Technical Centre for Tropical Forestry (Centre Technique Forestier Tropical – CTFT, according to its acronym in French), currently known as the French Agricultural Research Centre for International Development (Centre de coopération internationale en recherche agronomique pour le développement – CIRAD, according to its acronym in French), and ONF between 1972 and 1976. The relative standard variation of the volume was controlled and estimated between 3 percent and 6 percent. A post-stratification into three forest types – "terra firme forest", "swamp forest" and "secondary forest" – improves the precision.

More recently, the so-called "habitats" inventory, carried out between 2006 and 2014 (and still in progress) by a group of institutions comprising the ONF, the Guiana Amazonian Park, French Biodiversity Agency (Office Français de la Biodiversité), French National Research Institute for Sustainable Development and CIRAD, aims to produce models for estimating forest variables on a "national" scale, using rapid assessment methods and at a relatively low cost (Guitet, Brunaux *et al.*, 2016).

This model-dependent approach relies on a nested multiscale sampling, where field plots have been disseminated according to a pre-stratification based on the nature of the cover elaborated by SPOT Vegetation satellite image processing (Gond *et al.*, 2011) and on geomorphological landscape types (Guitet *et al.*, 2013), taken as indicators of the regional variability of forest ecosystems (Guitet, Hérault *et al.*, 2015).

In addition, the so-called "Kyoto" inventory aimed at providing information on land use changes between 1990, 2008 and 2012. Carried out in 2014 by ONF and IGN (Lefèbvre and Verger, 2014), it is a one-phase stratified systematic inventory based only on the photo interpretation of LANDSAT and SPOT satellite images.

Finally, an exhaustive vegetation map of French Guiana, with a resolution of 0.5 ha, was drawn up by the IGN (IGN, 2018; Guitet, 2018). This map was produced by merging different thematic products of the same vintage and derived from SPOT-6 and SPOT-7 images (map of mangroves, land use map and map of non-forest habitats). It has been post-processed by photo interpretation on the basis of a SPOT-7 and Pléiades mosaic for the year 2015 in order to distinguish the different forest classes, as per the classification developed by the Food and Agriculture Organization of the United Nations (FAO).

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TABLE 16.1

Historical description of various inventories conducted

Territory	Inventory	Execution period	Level	Sampling design	Number of sampling units
Guadeloupe	Vegetation map	2017	National	None; wall-to-wall land use map based on remote-sensing and photo interpretation	Not applicable
Martinique	Land use maps	2017	National	None; wall-to-wall forest map based on remote-sensing (10 cm resolution aerial images) and photo interpretation	Not applicable
French Guiana	"Au millième" inventory	1962 to 1970	Subnational	Regularly spaced north to south line transects from coastal area up to 145 km inland, covering 3 053 800 ha	25 temporary field line transects with variable length and irregularly divided regarding geological basement Sampling rate 0.1%
	"Papetier" inventory	1972 to 1976	Subnational	Systematic sampling along regularly spaced transects in 14 independent blocks from 20 000 ha to 78 000 ha, covering 546 900 ha	0.5 ha field plots of 25 m by 200 m, spaced every 200 m to 400 m along the transect Sampling rate 0.2% to 0.8%
	"Habitats" inventory	2006 to 2014	National	Stratified model-dependent and multiscale design	3 132 field plots of 0.2 ha each on 111 line transects in 33 sites Sampling rate 0.013 %
	"Kyoto" inventory	2014	National	One-phase stratified systematic sampling limited to remote-sensing data in three different years (1990, 2008 and 2012)	20 500 photo-interpretated circular plots of 0.5 ha
	Forest map	2018	National	None; wall-to-wall forest map based on remote-sensing and photo interpretation (Pléiades and SPOT-7)	Not applicable

Source: Prepared by the authors.

16.2 TERMS AND DEFINITIONS

For the Global Forest Resources Assessment (FRA) reporting, definitions and thresholds have been harmonized between the overseas territories, as well as with metropolitan France (see Table 16.2). However, in metropolitan France, the minimum DBH threshold is lower (7.5 cm). More importantly, contrary to French Guiana, Martinique and Guadeloupe, the FRA assessment is based on a two-phase sampling design relying on field measures.

Forest

A forest is defined according to the FRA international criteria as land with a minimum land area of 0.5 ha, with at least 10 percent crown coverage, and a tree height of at least 5 m (FAO, 2018). It includes plantations and natural regrowth on closed mines (where forest reconstitution is a legal obligation). This definition excludes woody regrowth on traditional and conventional agriculture areas (as local agriculture includes fallows), which constitute "other land". "Other wooded land" includes natural bushy vegetation but also non-forested areas on abandoned mines (French Guiana). The areas are only extracted from maps where all the criteria needed to define the forest cannot be properly assessed. The uncertainty of the values generated and the probable biases are unknown.

Volume

Volume is defined as the stem volume of all living trees over 10 cm DBH or above the buttresses if these are higher (relevant essentially for French Guiana). It includes the stem volume from the ground or at stump height, up to 7 cm in diameter (stem top). In French Guiana, the volume of stems between 10 cm and 17.5 cm in diameter is estimated from the "papetier" inventory as a constant fraction of 15 percent of the volume of stems greater than 17.5 cm, which is calculated at the tree level thanks to

volume models (Gazel, 1983) and added accordingly. In the Caribbean, the estimation is even less precise and the result of the choice of experts.

Biomass

Biomass corresponds to aerial living biomass of all living trees over 10 cm DBH. In French Guiana, the global equation of Chave *et al.* (2014) has been used. In the Caribbean islands, the biomass is inferred from uncertain expert values (Durrieu de Madron, 2008).

16.3 SAMPLING DESIGN FOR FRENCH GUIANA

The current assessment of forest resources in French Guiana and the Caribbean does not rely on sampling designed inventories. Indeed, the last reported forest areas all rely on simple mapping approaches based on the best available remote-sensing data. Figure 16.1 illustrates the maps resulting from this approach in Martinique.

The sampling strategies for the French overseas territories still need to be defined, tested and compared after a decision has been taken regarding their implementation. Sampling designs as such have only been employed in French Guiana; these have been either limited in space or restricted to a single photo-interpreted phase with no field assessment (see Figure 16.2). A short description of the latest assessments is provided hereafter:

FIGURE 16.1

Land cover map of Martinique derived from photo interpretation of 10-centimetre aerial coverage (2017)

The boundaries shown and the names and designations used on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any countries, territories, cities, areas, authorities, or delimitation of their frontiers or boundaries. Dotted lines on maps represent approximate boundaries for which there may not yet be full agreement.

Source: Prepared by the authors.

TABLE 16.2

Definitions used to implement the Global Forest Resources Assessment report in 2020

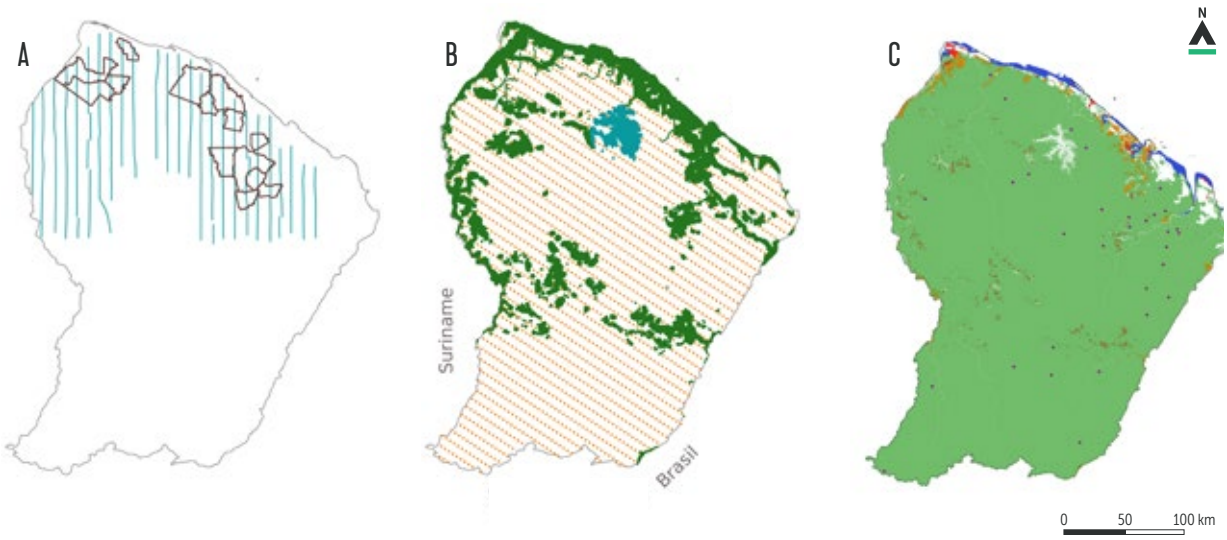
Term	Definition	Variables and thresholds
Forest	Land spanning more than 0.5 hectares with trees higher than 5 metres and a canopy cover of more than 10 percent, or trees able to reach these thresholds *in situ*. It does not include land that is predominantly under agricultural or urban land use.	Area ≥ 0.5 ha Canopy cover ≥ 10 % Tree height ≥ 5 m
Volume	Stem volume of all living trees over 10 cm diameter at breast height (DBH) or above the buttresses if these are higher. It includes the stem volume from the ground or at stump height, up to 7 cm in diameter (stem top).	DBH ≥ 10 cm Stem top limit = 7 cm
Biomass	Aerial living biomass of all living trees over 10 cm DBH	DBH ≥ 10 cm

Source: **FAO.** 2018. *Global Forest Resources Assessment: Terms and definitions FRA 2020.* Forest Resources Assessment Working Paper 188. Rome, FAO.

- "Papetier" inventory (Figure 16.2, map A): A total of 14 independent blocks ranging from 20 000 ha to 78 000 ha and collectively covering 546 900 ha. In each block, a regular systematic sampling was established and organized thanks to regularly spaced transects, along which plots were also regularly installed. The distance between transects (1 050 m, 1 550 m or 3 100 m) and between plots along the transects (200 m or 400 m) varied between blocks, but was fixed for a given one. Post-stratified estimates have been produced (Guitet *et al.*, 2014).
- "Kyoto" inventory (Figure 16.2, map B): Design-based estimates (totals and confidence interval) have been calculated through a one-phase (photo-interpreted only) stratified systematic sampling. The territory was divided into three strata with two sampling intensities based on a common 466-metre square grid. In two strata (R for reinforced where important changes are awaited and P for Petit Saut, a buffered area around the large watershed of the Petit Saut hydropower dam), one point out of every four was selected, resulting in a 932-metre square grid, while elsewhere (N for normal strata), the grid was rectangular, measuring 8 388 m by 4 194 m. The interpretation was conducted on the same sample during three different years (1990, 2008 and 2012) in order to calculate the land use changes. This work was conducted using the best available remote sensing sources on the different dates. Therefore, the interpretation was successively conducted on Landsat Thematic Mapper in 1990, SPOT-2, SPOT-4, and SPOT-5 in 2008, and SPOT-5 in 2012. Altogether, 20 499 points were selected and the photo interpretation was conducted on 5 000 square metres (m²) circular plots (Lefèbvre and Verger, 2014).
- "Habitats" inventory (Figure 16.2, map C): A total of 33 sites disseminated across the whole territory after a stratification, but not randomly drawn. Two to four transects starting from the selected point in different directions were chosen to best represent the local variability (Guitet, Brunaux *et al.*, 2015).

FIGURE 16.2

Partial inventories and maps in French Guiana



The boundaries shown and the names and designations used on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any countries, territories, cities, areas, authorities, or delimitation of their frontiers or boundaries. Dotted lines on maps represent approximate boundaries for which there may not yet be full agreement.

Notes: A: Old inventories, where the blue lines correspond to the "au millième" inventory and the brown polygons are the blocks of the "papetier" inventories. B: The "Kyoto" inventory, wherein the colours distinguish the three strata (normal in orange, reinforced in green, and specific to Petit Saut in blue). C: The 2018 vegetation map in which the "habitat" inventory points appear in violet. The forests are in green; the mangroves in blue; red corresponds to artificial land cover; and orange to agricultural lands.

Source: Prepared by the authors.

16.4 DESIGN OF THE SAMPLING UNIT

This section describes the different field plots used in French Guiana's statistical inventories, which were listed in the preceding section:

- "Papetier" inventory: rectangular 0.5 ha plots of 25 m in width and 200 m in length, every 200 m to 400 m along transects (Guitet *et al.*, 2014); see Figure 16.3.
- "Habitats" inventory: rectangular 0.2 ha non-permanent field plots belonging to the 33 sites distributed all over the territory. Two to four 3 km long transects were opened at each site in different directions in order to represent the geological and topographical diversity of the site. Each 20 m wide transect was divided into 100 m segments, such that the basic sampling units were 0.2 ha plots, nested within transects, which themselves were nested within sites. All trees (including palms) greater than 17.5 cm DBH (at a height of 1.3 m or above the buttresses) were identified using a standardized vernacular nomenclature refined to correspond either to botanical species, genera or families (Guitet *et al.*, 2014). This nomenclature proved to be 83 percent accurate at the family level and 74 percent accurate at the level of the most precise botanical equivalent of vernacular names (that is, the species, genus or family level) depending on the precision reached for the vernacular name (Guitet *et al.*, 2014). Diameters were measured by classes of 5 cm (for example, 20 cm for diameters between 17.5 cm and 22.5 cm, etc.). Height and precise diameter were estimated using allometries calibrated on permanent research plots (Guitet, Hérault *et al.*, 2015).
- "Kyoto" inventory: 0.5 ha circular photo plots. No field measurements were taken.

16.5 CALCULATION OF LAND AREA, VOLUME AND BIOMASS

With respect to the calculations employed for land area, volume and biomass, the situation differs broadly between the two main regions examined here (see Table 16.3).

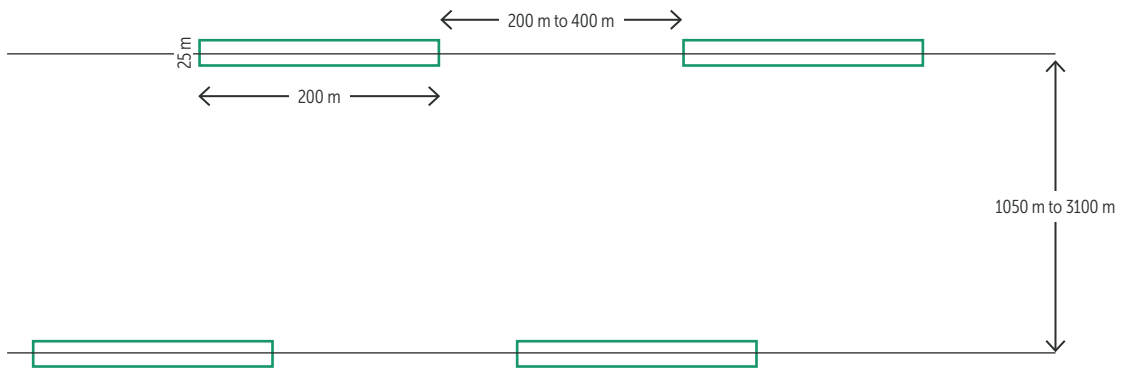
16.5.1. LAND AREA CALCULATION

Caribbean islands

The forest area calculation for the Caribbean islands results from a mapping approach. The different maps produced have implemented the international (FAO FRA) definition of forests, insofar as such work is possible through photo interpretation alone and the use of various remote sensing sources. For Martinique and Guadeloupe, at least, some ground control operations have been conducted to validate the most uncertain land area calculations. To date, no estimation error is available.

FIGURE 16.3

Sampling unit configuration of the "papetier" inventory



Note: Rectangular plots measuring 25 m by 200 m every 200 m to 400 m along a line transect.
Source: Prepared by the authors.

TABLE 16.3

Equations used for volume and biomass/carbon calculations

Country/region	Variables	Source of information	Reference
Guadeloupe and Martinique	Total volume (m^3)	Constant value per forest type (six categories)	Durrieu de Madron (2008)
	Biomass (kg)	Aerial biomass: constant value per forest type (73 t/ha)	Durrieu de Madron (2008)
French Guiana	Total volume (m^3)	Model-dependent estimate	Tree volume equations: Gazel (1983) Estimation: Guitet, Hérault *et al.* (2016)
	Biomass (kg)	Model-dependent estimate (map)	Biomass allometry: Chave *et al.* (2014) Estimation: Guitet, Hérault *et al.* (2016)
All	Carbon	Constant fraction of 47% or 47.5% of the biomass	Experts' choice

Source: Prepared by the authors.

French Guiana

In this territory, the land area has been assessed once through a sampling approach (Lefèbvre and Verger, 2014). However, for the purposes of FRA reporting, the choice has been made to refer to a vegetation map dated 2015 (Guitet, 2018).

16.5.2. VOLUME AND BIOMASS

Caribbean islands

The volume and biomass have been derived from average values per unit area as proposed by Durrieu de Madron (2008) and roughly based on a limited set of experimental plots. The calculation has been conducted by local experts and thus represents a first approximation of the forest resources and cannot be taken as a proper estimate.

For biomass, the approximate values of Durrieu de Madron are potentially overestimated when compared to another local study. Nevertheless, these values have been retained here for the sake of consistency with the FRA reporting.

In conclusion, for all the Caribbean islands, the reported values are derived simply, through sets of coefficients provided by experts from a mapped area of forest. None of these approaches constitutes a reliable, robust and trustworthy estimation process.

French Guiana

The following two sources of field data have been used to infer the volume and biomass of French Guiana's forests:

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- The "papetier" inventory, conducted by CTFT between 1972 and 1976, constitutes a stratified systematic sampling design with 0,5 ha plots (25 m by 200 m) every 200 m or 400 m along transects at 1 050 m, 1 550 m or 3 100 m intervals. The inventoried region of 546 900 ha is situated in the north of the territory, along the coastline. The DBH threshold varied among strata from 10 cm to 20 cm. A total of 290 species or species groups were distinguished. Volume models have been adjusted from 534 cut trees (from 10 cm to 80 cm DBH).

- The "habitat" inventory (2006–2014) was conducted by ONF on 33 sites spread across the entire territory, stratified by geomorphological units. The site positions have been chosen to be both representative and accessible. The volume calculated on these sites has been inferred from a set of local calculations (Gazel, 1983). The volume is calculated for all trees with DBH of 17.5 cm or greater as the stem volume above stump. The stem top (measuring less than 7 cm) is excluded.

The forest biomass in 2015 has been estimated through a model-dependent approach in two specific studies (Guitet, Hérault *et al.*, 2015) combining the field measurements from the two previously mentioned inventories and remote sensing data. The map produced as a result covers the entire territory. The tree biomass used to adjust the models has been calculated using the pan-tropical allometric equation of Chave *et al.* (2014). The biomass map, combined with the forest type map, contributed to providing the average biomass values (tonnes per hectare) used in the FRA 2020 report and further transformed into tonnes of carbon per hectare.

TABLE 16.4

Results of the most recent cycle of forest inventories

Country / region	Variable	Result	Description
Guadeloupe	Area (1 000 ha)	72.1	2017 values
	Volume (million m^3)	26.5	
	Biomass (t/ha)	347	Aerial biomass
	Carbon (t/ha)	165	47.5% of the biomass
Martinique	Area (1 000 ha)	51.7	2017 values
	Volume (million m^3)	14.4	
	Biomass (t/ha)	306	Aerial biomass
	Carbon (t/ha)	145	47.5% of the biomass
French Guiana	Area (1 000 ha)	8 020	2016 values
	Volume (million m^3)	2 646	
	Biomass (t/ha)	365	Aerial biomass
	Carbon (t/ha)	171.6	47% of the aerial biomass

Source: Prepared by the authors.

16.6 RESULTS OF THE MOST RECENT FOREST INVENTORY

As explained in section 16.1, none of the territories has had a proper forest inventory. The results presented here are those provided for the FRA 2020 and produced through the combination of multiple approaches. In the Caribbean islands, the forest areas are directly extracted from maps, further transformed into volume, biomass and carbon thanks to sets of constant coefficients. No error estimates are provided as they cannot be inferred from these non-statistical approaches.

As a consequence, the results provided in Table 16.4 are not fully reliable. They represent an initial rough attempt to provide orders of magnitude, but are certainly not estimates.

16.7 IMPLEMENTATION AND QUALITY CONTROL

No quality control exists to date. However, new missions conducted between 2016 and 2022 as a follow-up to the "habitat" inventory will facilitate the assessment of the accuracy of predictions within a few years, especially for biomass estimates.

16.8 OTHER RELEVANT VARIABLES COLLECTED

Significant work has been conducted in French Guiana to describe the forest types, habitats and related fauna during the recent and ongoing "habitat" inventory, including the following:

- physical and chemical properties measured on soil cores and pits;
- understorey vegetation inventoried on 25 m^2 plots;
- kilometric abundance indices of large mammals and birds calculated on line transects;
- canopy parameters (opening, height, gaps) and understorey structures (palm density).

This work has produced a catalogue of forest habitats (Guitet, Brunaux *et al.*, 2015) and the related map, which was further used to derive the biomass map (Guitet, Hérault *et al.*, 2015).

Soil carbon has been assessed using soil cores and pit analysis in the laboratory. A model-dependent estimation at the territory scale has been produced (Guitet, 2016). Soil carbon maps have also been produced in Martinique using a soil and land use vector map with unspecified resolutions (Blanchard and Bernoux, 2005).

16.9 FUTURE PROSPECTS

As explained in the introduction, there is currently no statistical forest inventory in the French territories of Latin America and the Caribbean, even though the implementation of such inventories has been foreseen by the law since 2014.

In 2018, a specific study by IGN described the possible approaches that could be deployed. The report (IGN, 2018) proposes a three-step answer:

1. contour map of the forest with the possible distinction of different forest types;
2. complete land use map covering not only forests, but the whole territory;
3. statistical forest inventory.

For all the territories examined in this chapter, the first step has been completed at least once and, in some cases, more frequently. The second item is available in Martinique and is in progress in Guadeloupe. However, the third item, corresponding to a real NFI, is still missing in all territories and has not yet begun.

However, the situation is markedly different between regions. In the Caribbean, deploying a forest inventory is not a major issue as the forest surface is restricted and most areas are easily accessible, even if very steep at times. Thus, a classic systematic two-phase sampling plan, comparable to what is done in metropolitan France, can certainly be envisioned. Its practical implementation is primarily a policy decision to allow the necessary financial resources needed for its realization.

In French Guiana, the situation is far more complex, as the neighbouring countries that have already started such an inventory are well aware. Indeed, the great diversity and poor accessibility of the Amazonian forests will certainly lead to a limited number of plots of larger size and generally grouped in clusters. The classical design-based approach of forest inventories may not be applicable in this territory. No specific study has begun yet, but the invaluable experience of the other countries will be essential to work on the sampling plan, harmonize the methods and ensure the comparability of the results to come.

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NEXT CHAPTER

HONDURAS

Chapter 17

HONDURAS

NATIONAL FOREST INVENTORY OF HONDURAS

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17.1 HISTORICAL OVERVIEW OF NATIONAL FOREST INVENTORIES IN HONDURAS

The first National Forest Inventory started in the mid-1960s, technically and financially supported by the Food and Agriculture Organization of the United Nations (FAO). The main focus of this inventory was the assessment of forest resources in terms of timber stocks, primarily for industrial purposes (ICF, 2017a). Several forest inventories were subsequently conducted in Honduras in administrative regions that were of interest for productive development; these include the assessment carried out in 1983 by the Japan International Cooperation Agency in the region of La Mosquitia and the National Forest Inventory (INFONAC) of 1981, implemented with the collaboration of the Canadian International Development Agency (CIDA). This last project was carried out in the central region of the country, where forest production was quantified, in addition to developing volume models for coniferous forest and some broadleaved species (AFE-COHDEFOR, 2005).

In 2005, Honduras was selected by the FAO Global Forest Resources Assessment (FRA) programme as one of the countries where a national forest inventory combining biophysical and socioeconomic aspects of forest use would be established. This first measurement cycle was called the Honduran national forest assessment (NFA), implemented by the State Forestry Association, Honduran Forestry Development Corporation (Asociación Forestal del Estado, Corporación Hondureña de Desarrollo Forestal – AFE-COHDEFOR, according to its acronym in Spanish), which is now called the National Institute for Forest Conservation and Development, Protected Areas and Wildlife (Instituto Nacional de Conservación y Desarrollo Forestal, Áreas Protegidas y Vida Silvestre – ICF, according to its acronym in Spanish). This process was carried out in coordination with the Ministry of Agriculture and Livestock (Secretaría de Agricultura y Ganadería). The NFA, which ended in 2006, resulted in the *Manual for the field survey of the national forest assessment* (AFE-COHDEFOR, 2005); this served as the basis for subsequent field manuals and measurement cycles. In addition, the *Report on the Results of the 2005–2006 Forest and Tree Inventory* (AFE-COHDEFOR, 2006) was published, which documents the entire process of methodological development, operation and implementation of the NFA and reports on the state of Honduras' ecosystems in accordance with the criteria, indicators and variables established for the NFA.

The planning and execution of the second measurement cycle, called the National Forest and Biodiversity Assessment (Evaluación Nacional Forestal y de Biodiversidad – ENFB, according to its acronym in Spanish), began in 2010. It was led by the ICF, with financial support from the European Union through the projects "Strengthening of local management of natural resources in the Patuca, Choluteca and Negro river basins" and "Modernization of the Forestry Sector in Honduras" (MOSEF), with technical assistance from the International Programs office of the United States Department of Agriculture Forest Service.

The implementation of the ENFB was concluded in 2015, generating significant outputs for the country, such as the *Field manual for the establishment of sampling units and*

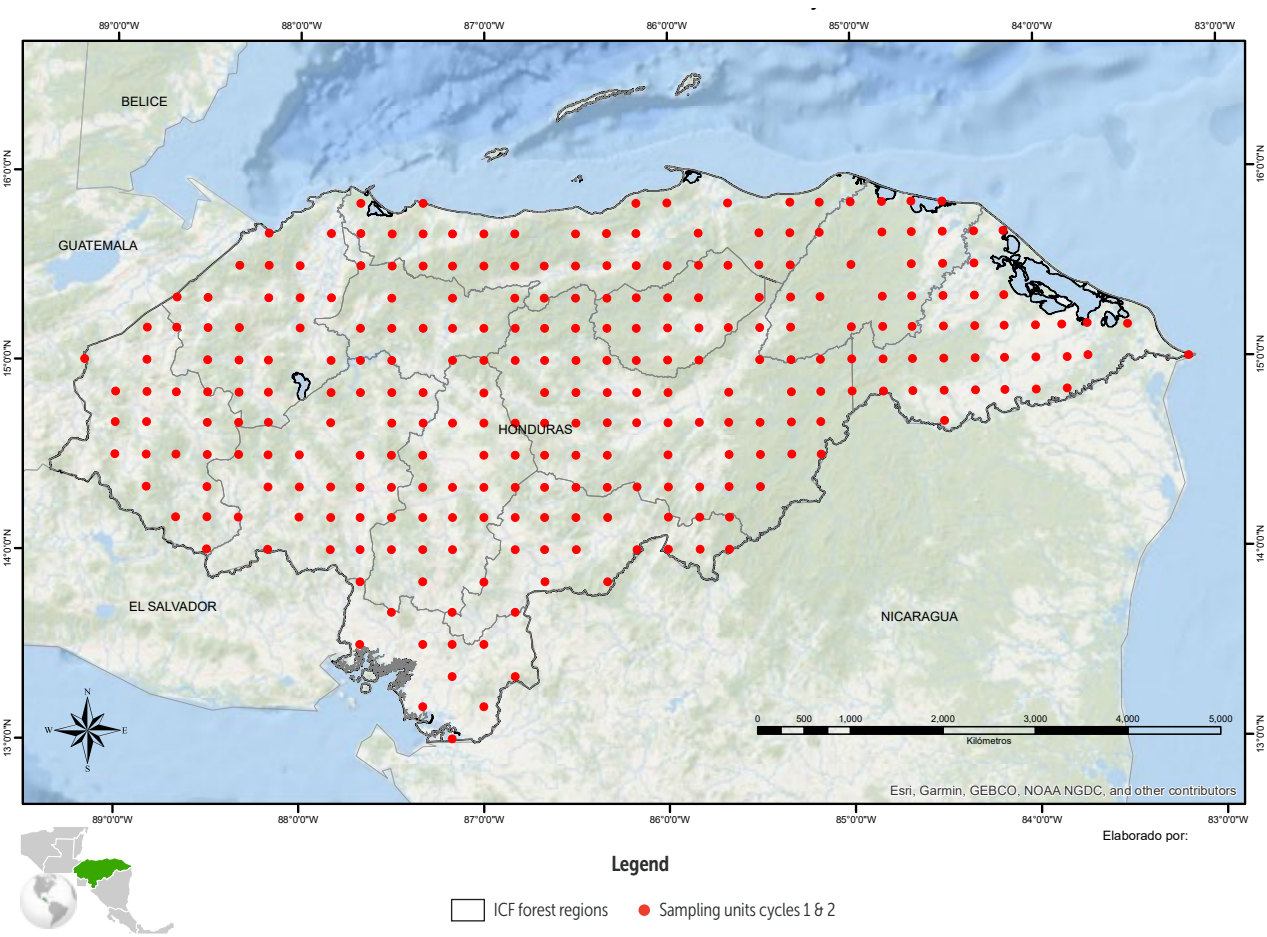
plots 2014–2015 (ICF, 2014a) and *Procedures for calculations in the NFI database of Honduras* (ICF, 2016), the latter of which provides instructions for data processing and analysis. Reports assessing the biodiversity in different regions of the country were also generated. Finally, the document *Results of the national forest assessment of Honduras* (ICF, 2017a) was prepared, which calculated the variables assessed by the ENFB and generated trends for the period 2005–2015 based on the results of the first and second measurement cycle. In general, the results reflected the state of the ecosystems and served as inputs to support decision-making within the country's forestry sector.

In both measurement cycles, the results focused on calculating the variables established for the NFA and ENFB, whose respective criteria and indicators were adopted from the Lepaterique Process of Central America on Criteria and Indicators for Sustainable Forest Management (CCAD, 2004). In summary, the national forest inventory aims to assess the country's ecosystems considering main criteria such as forest cover, health and vitality, productive functions, environmental services, biodiversity, improvement of social, economic and cultural benefits, as well as the state of forest plantations and agroforestry systems.

The results generated with the first two measurement cycles (NFA and ENFB) were also part of Honduras' international initiatives and commitments under the United Nations Framework Convention on Climate Change (UNFCCC). More specifically, biomass, carbon and carbon dioxide (CO_2) estimates were included in the emission

FIGURE 17.1

Map of sampling units of the first and second cycles of National Forest Inventory



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Source: **ICF (National Institute for Forest Conservation and Development, Protected Areas and Wildlife).** 2017b. Manual para la colecta de datos de campo para el Inventario Nacional Forestal de Honduras. Tegucigalpa.

factors section of the Honduran Forest Reference Level document, presented within the framework of the Reducing Emissions from Deforestation and Forest Degradation (REDD+) mechanism. In addition, this information was included for the land use, land use change and forestry (LULUCF) sector in the report generated through the National Greenhouse Gas Inventory (NGHGI) of Honduras.

The third measurement cycle was called the National Forest Inventory (NFI) and was led by the ICF. The NFI took place between 2017 and 2021, which included the development of a new methodological design based on the updated information needs and demands of the forestry sector. This new design was based on data from the two previous measurement cycles (NFA and ENFB). Statistical analyses regarding costs, time and accuracy of the NFI were carried out by the International Programs office of the United States Department of Agriculture Forest Service. These analyses recommended changing the shape and size of the plots that made up the sampling unit (SU); likewise, the number of variables associated with the NFI criteria and indicators was reduced, due to the difficulty of collecting and analysing them.

Despite the aforementioned changes, the third measurement cycle included the evaluation of most of the variables of the Lepaterique Process, except those related to the biodiversity of fauna, typification of owners and communities, as well as techniques and technologies for forest resource use. The new design considered increasing the number of samples at the national level, including the remeasurement of the SUs inventoried in the first and second measurement cycle (Figure 17.1), in order to monitor the change dynamics between cycles.

During this third measurement cycle, the processes of data collection, processing, analysis and generation of NFI reports were institutionalized, in the sense that technical staff from the ICF undertook the coordination and implementation of activities.

The advantages of the new methodology include a significant reduction in the field survey costs, considering that the two previous measurement cycles were carried out by external consultants, which represented a significant economic cost.

Other benefits generated during the third cycle include reduced field survey times, increased sampling intensity, and the implementation of a continuous monitoring system, thereby contributing to the capacity development of the ICF's technical staff. In addition, reports were generated on an annual basis, considering that 20 percent of the total SUs were collected each year during the five-year cycle (2017–2021). Figure 17.2 shows the national distribution of SUs for the third measurement cycle.

Finally, the size and shape of the SUs facilitated the integration of field data into models based on Geographic Information Systems (GIS) and remote sensing, thus generating more accurate results that included statistical estimates based on field data and the calculation of land areas with their spatial location drawn from satellite images. Overall, these changes contribute to meeting the information needs for strategic planning at the national level.

In addition, these changes enable the country to integrate NFI results into various international processes and commitments, such as National Communications, NGHGI, Biennial Update Reports (BUR), nationally determined contributions (NDC), REDD+ initiatives (Forest Reference Level and National Forest Monitoring System) and their respective measurement, reporting and verification (MRV) modules.

Table 17.1 describes the main characteristics of the measurement cycles of the national forest inventories carried out in Honduras, as well as changes that have taken place over time.

TABLE 17.1

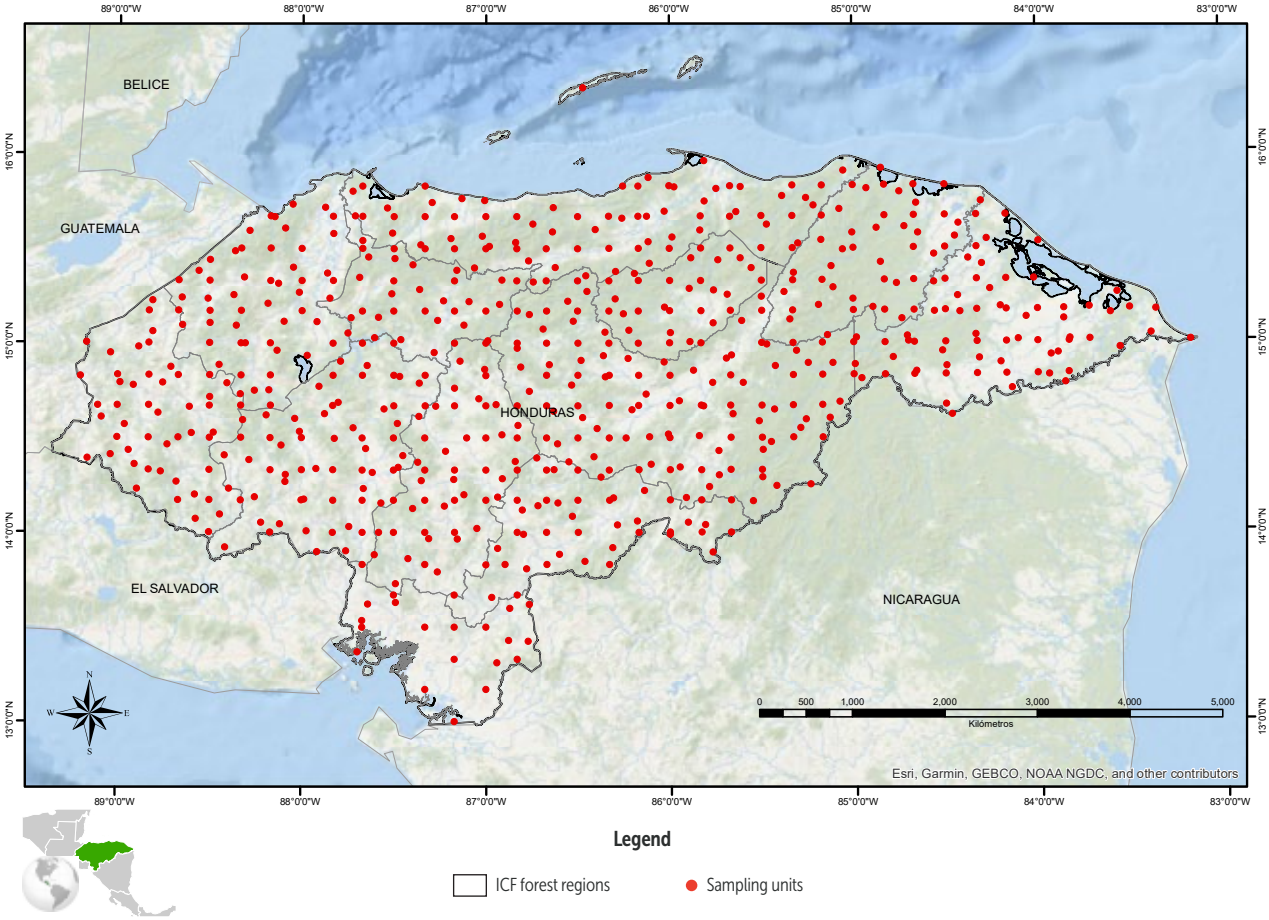
Historical overview of national forest inventories in Honduras

Inventory cycle	Implementation period	Scale	Sampling design	Number of sampling units	Number of plots
NFA (cycle 1)	2005–2006	National	Systematic	181	724
ENFB (cycle 2)	2011–2015	National	Systematic	263	1 052
NFI (cycle 3)	2017–2021	National	Random/balanced	635	1 905

Source: Prepared by the authors.

FIGURE 17.2

Map of the sampling unit grid used for the third measurement cycle of the National Forest Inventory



The boundaries shown and the names and designations used on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any countries, territories, cities, areas, authorities, or delimitation of their frontiers or boundaries. Dotted lines on maps represent approximate boundaries for which there may not yet be full agreement.

Source: **ICF.** 2017b. *Manual para la colecta de datos de campo para el Inventario Nacional Forestal de Honduras.* Tegucigalpa.; **FAO.** 1998. *FRA 2000: Terms and definitions.* Forest Resources Assessment Working Paper 1. Rome, FAO.

17.2 TERMS AND DEFINITIONS RELEVANT TO THE IMPLEMENTATION OF THE NATIONAL FOREST INVENTORY IN HONDURAS

The definition of forest used for the National Forest Inventory of Honduras was adapted from FRA 2000 (FAO, 1998), and it has been used continuously since the first measurement cycle in 2005. A more specific classification of forest types was also developed, based on FAO global classes and other classes used in the country by public and private institutions and projects.

Table 17.2 shows the terms and definitions for forest, trees outside forests, forest types, other wooded land and other land.

TABLE 17.2

Summary of definitions used to implement the National Forest Inventory of Honduras

Term	Definition	Variables and thresholds
Forest	An association of natural or planted plant species – at any stage of the natural life cycle, with trees over 5 m high and a canopy cover greater than 10 percent, extending over 0.5 ha and with a minimum width of 20 m – which is capable of producing goods and services, influencing the climate and water and soil systems, and providing habitat for wildlife, whether or not it is managed (FAO, 1998). The term specifically excludes tree formations used in agricultural production systems, e.g. fruit plantations and agroforestry systems. The term also excludes trees growing in urban parks and gardens. Note: the width of 20 m must be met as a minimum distance using the base of the trees and not to the crowns. It is also important to note that for the National Forest Inventory (NFI), the minimum area of 0.5 ha should consist of only one type of forest (coniferous, moist broadleaved, dry broadleaved, mixed broadleaved, etc.). For example, in an area of 0.6 ha where half of it is coniferous forest and the other half broadleaved forest, these areas are not considered forest, but wooded lands.	Minimum area: 0.5 ha Tree height: ≥ 5 m Canopy cover: ≥ 10%
Evergreen broadleaved forest	Forest in which more than 75% of the tree cover is composed of broadleaved species (FAO, 1998). Tree leaves remain green throughout the year and have no or minimal deciduous leaves.	
Dry forest	Forest with deciduous and thorny species, cacti and species such as charcoal, calabash tree, common lignum vitae, guanacaste and others. The rainfall pattern is well defined with long periods of drought and high temperatures (ICF, 2017b).	
Coniferous forests	Forest in which more than 75% of the tree cover consists of coniferous species (FAO, 1998). These are forest areas of pine trees at different stages of maturity.	
Mixed forest	Forest of broadleaved and coniferous species where neither of them exceeds 75% of the tree cover (FAO, 1998). These are areas with a combination of pine and other broadleaved species such as oak, holm oak, mountain nance, etc. All forest strata must be considered to identify the dominance of conifers or broadleaved trees, which can be juveniles or adults.	
Mangrove forest	Forest dominated by a group of tree and shrub species that have evolved physiological, reproductive and structural adaptations that allow them to colonise unstable substrates and flooded areas, subject to tidal changes on tropical and subtropical swell-protected coasts (ICF, 2017b).	
Other wooded land	Natural land not classified as "forest" spanning over an area larger than 0.5 ha; with trees over 5 m in height and/or capable of reaching this height at maturity, with a canopy cover of 5% to 10%; can also consist of a combination of trees, shrubs and bushes (FAO, 1998).	Minimum area: 0.5 ha Tree height: ≥ 5 m Canopy cover: between 5% and 10%
Other land	Land that has not been classified as forest or other wooded land. It includes agricultural land, natural grasslands, land with buildings, unproductive land, etc. (FAO, 1998).	
Volume	Volume over bark of all living trees with a minimum diameter at breast height (DBH) of 10 cm (or above buttress/support if higher). This includes the stem from ground level to a minimum top diameter of 0 cm, excluding branches (FAO, 1998). Honduras reports estimates of total above-ground tree volume. *Note: Other calculations are made upon request, such as commercial volume (up to commercial height), of stumps (height ≤ 3 m) and lying dead wood.*	DBH equivalent to 1.3 m above-ground level: ≥ 10 cm Diameter over 0 cm Living and dead trees are included. Branches, twigs, leaves, flowers, seeds and roots are excluded.
Biomass	The mass of the woody portion (stem, bark, branches) of living and dead trees, shrubs and bushes. Includes: above-ground biomass, stumps and roots (below-ground biomass). Excludes leaves, flowers, seeds (FAO, 1998). *Note: Honduras reports biomass calculations separately, using different equations according to the type of deposit (above-ground, below-ground, stumps, lying dead wood and leaf litter).*	

Source: **ICF.** 2017b. Manual para la colecta de datos de campo para el Inventario Nacional Forestal de Honduras. Tegucigalpa.

17.3 SAMPLING DESIGN

The NFI of Honduras consists of a sampling design based on the country's total land area (112,492 square kilometres [km²]). A resource assessment is carried out by collecting information in areas inside and outside forests, considering that the management of these resources must be taken into account in the National Land Management Plan (Plan Nacional de Ordenamiento Territorial – PNOT, according to its acronym in Spanish); the PNOT requires updated information on the resources in all productive areas within the country. In addition, this form of assessment also allows for a diagnosis regarding the recovery of degraded forest ecosystems (ICF, 2017b).

The distribution of the SUs of the NFI was random and spatially balanced, based on the methodology described in Lister and Scott (2009). The purpose was to establish a sampling system that provides a uniform assessment of the ecosystems present in the 12 ICF forest regions, thereby obtaining field data that is representative of all types of land cover. At present, the NFI consists of 635 SUs, which are made up of three circular plots; of this total, approximately 43 percent are remeasurement SUs that were surveyed in the first and second cycles. Therefore, 271 SUs are available for comparison and for estimating changes and trends during the three measurement periods.

The distribution of SUs for the third measurement cycle of the NFI consisted of the following steps, as described in ICF (2017b):

- The country's total land area was divided into 6 350 irregular polygons (Peano polygons) of equal area equivalent to 1 755 ha, using a script developed in Python language for ArcGIS software. The number of 6 350 polygons is ten times greater than the SUs to be surveyed in the third measurement. This has been done to ensure that the current SUs have a one-to-one relationship with the polygons; furthermore, this decision could support a future intensification of SUs in the inventory.
- In each of the polygons, a point was randomly selected that potentially represents the centre of the first of the three plots that make up the SU.
- The polygons where SUs had been established in the first and second measurements were taken as a reference for the establishment of the new SUs, considering the coordinates of plot 1 of these SUs. For this purpose, the ICF has a database to verify the SUs measured in the two previous cycles.
- Considering that there were already 271 SUs, an additional 364 points had to be selected to establish the new SUs, in order to complete the total of 635 SUs that had been defined for the third measurement cycle.
- The 271 polygons containing SUs from the first and second measurement cycles were not considered for the drawing of the 364 additional SUs, such that a total of 6 079 polygons were available. From this number, the 364 additional points were selected and distributed in a spatially balanced manner throughout the country. That is, 1 out of 16 polygons was systematically selected, with the first polygon (1 to 16) being randomly selected. Figure 17.3 shows the distribution of the SUs.
- Once the 635 points to establish the new SUs were selected, the year of measurement of each SU was assigned (year 1 to 5) (ICF, 2017b).

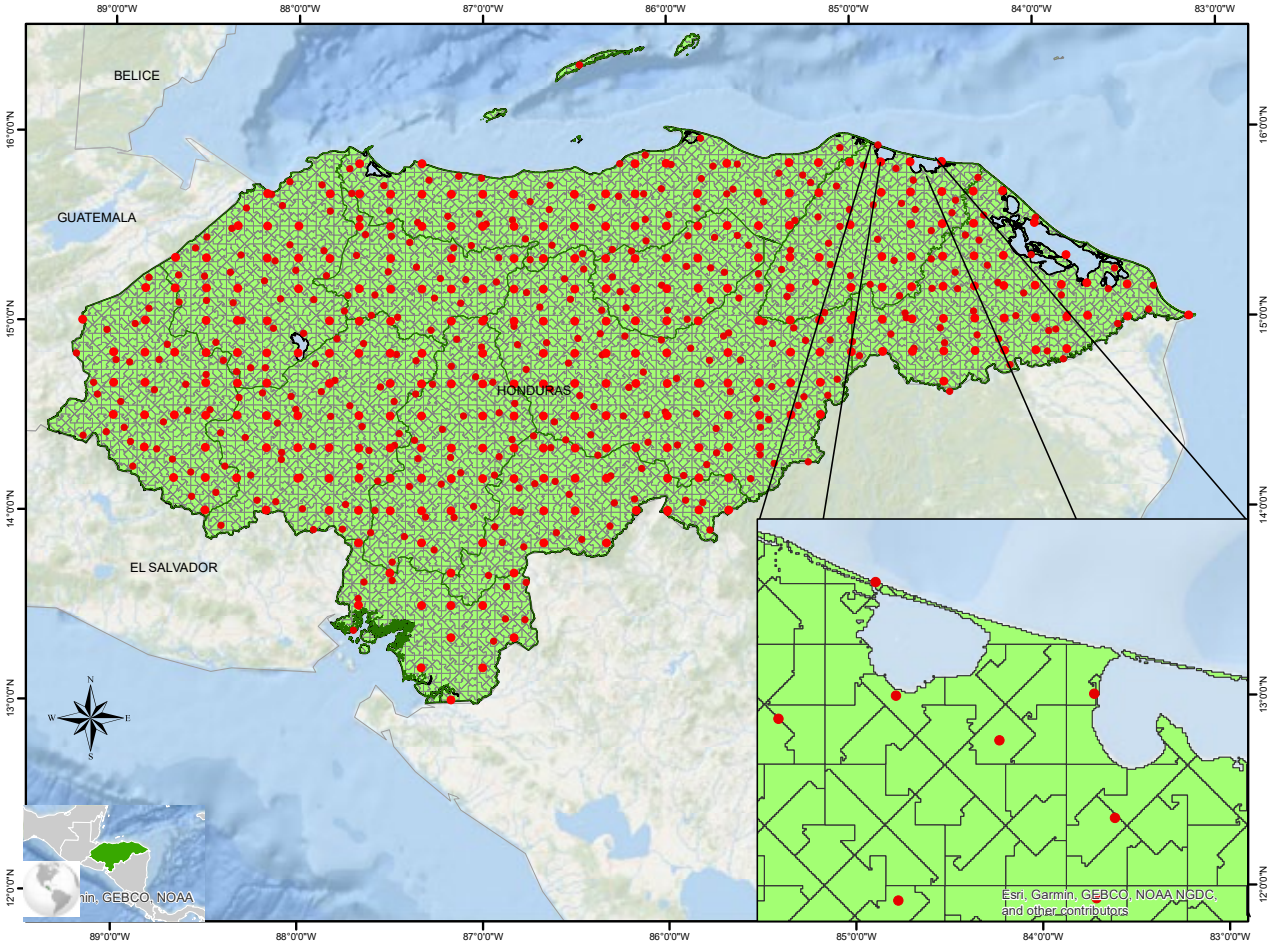
The division of the sample into five panels was done with the aim of distributing the measurement of the SUs over time, such that 20 percent of the samples were collected annually and reached 100 percent by the end of the fifth year, which marked the end of the third NFI measurement cycle. Figure 17.4 shows the distribution of SUs from 2017 to 2021.

The NFI of Honduras records the land cover types identified in the field, while also including the strata labels of the Forest and Land Cover Map of Honduras, from which the country's official figures on the land areas of different land cover types are generated (ICF, 2014b). This allows the country to generate estimates for both scenarios (field and remote sensing).

Table 17.3 shows the distribution of SUs according to the Forest and Land Cover Map of Honduras.

FIGURE 17.3

Map of random and balanced distribution of sampling units



The boundaries shown and the names and designations used on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any countries, territories, cities, areas, authorities, or delimitation of their frontiers or boundaries. Dotted lines on maps represent approximate boundaries for which there may not yet be full agreement.

Source: Prepared by the authors.

TABLE 17.3

Characteristics of the sampling design

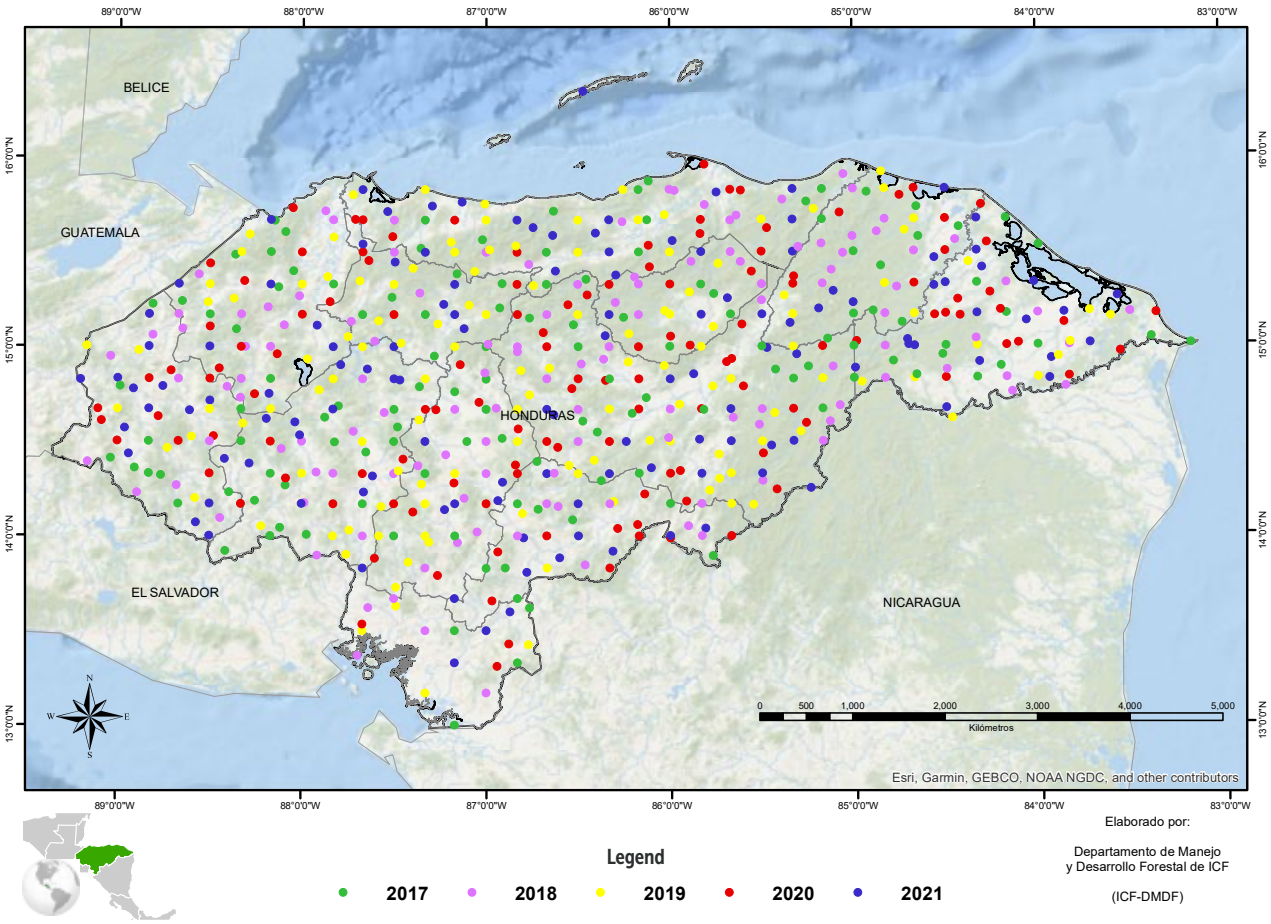
Name of the region	Total area (1 000 ha)	Number of sampling units or plots			Total number of sampling units or plots
		Forest	Other wooded land	Other land	
National	11 249.2	318 (SU)	112 (SU)	205 (SU)	635 (SU)
		954 (plots)	335 (plots)	616 (plots)	1 905 (plots)

Source: Prepared by the authors.

The distribution of SUs according to land cover types is shown in Figure 17.5, with measurement sites located inside and outside forested land.

FIGURE 17.4

Map of measurement panels of the third cycle of the National Forest Inventory of Honduras



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Source: Prepared by the authors.

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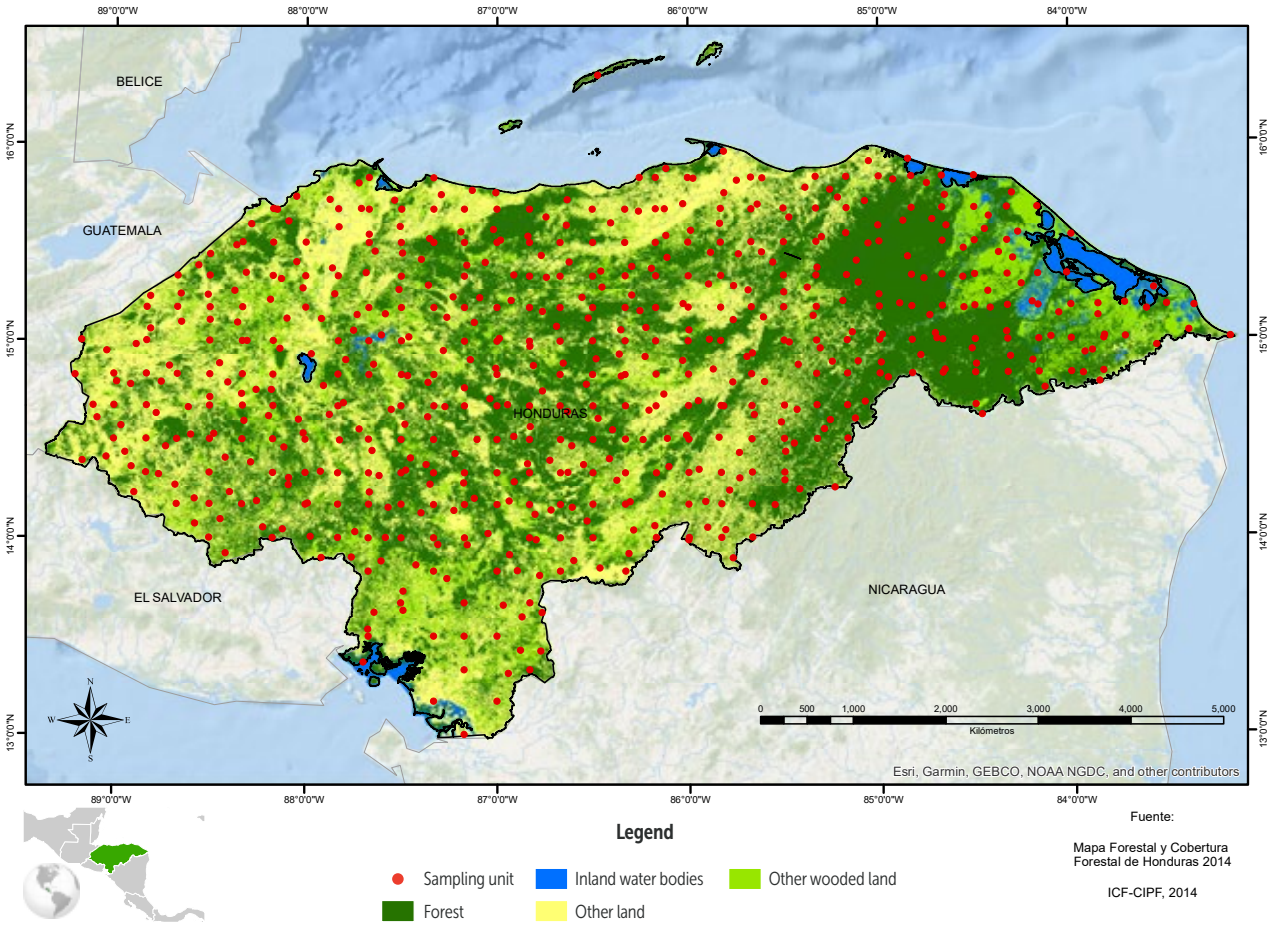
FIGURE 17.5

Map of sampling unit distribution by land cover type



The boundaries shown and the names and designations used on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any countries, territories, cities, areas, authorities, or delimitation of their frontiers or boundaries. Dotted lines on maps represent approximate boundaries for which there may not yet be full agreement.

Source: Prepared by the authors.

17.4 SAMPLING UNIT DESIGN

The SU design is a cluster consisting of three circular plots with a nested structure, oriented from south to north and with a distance of 50 metres (m) between each plot centre. Each of the plots has three circular subplots called nested plots (NP) with specific dimensions and types of measurement: NP 1 has a 15 m radius, NP 2 has a 6 m radius, and NP 3 has a 3 m radius, as shown in Figure 17.6.

Remeasurements of the SUs that were inventoried in the first and/or second measurement cycle were taken on the first plot of the old SUs, which consisted of clusters made up of four rectangular plots (20 m by 250 m). The main purpose of the SU overlap is to measure change dynamics between measurements.

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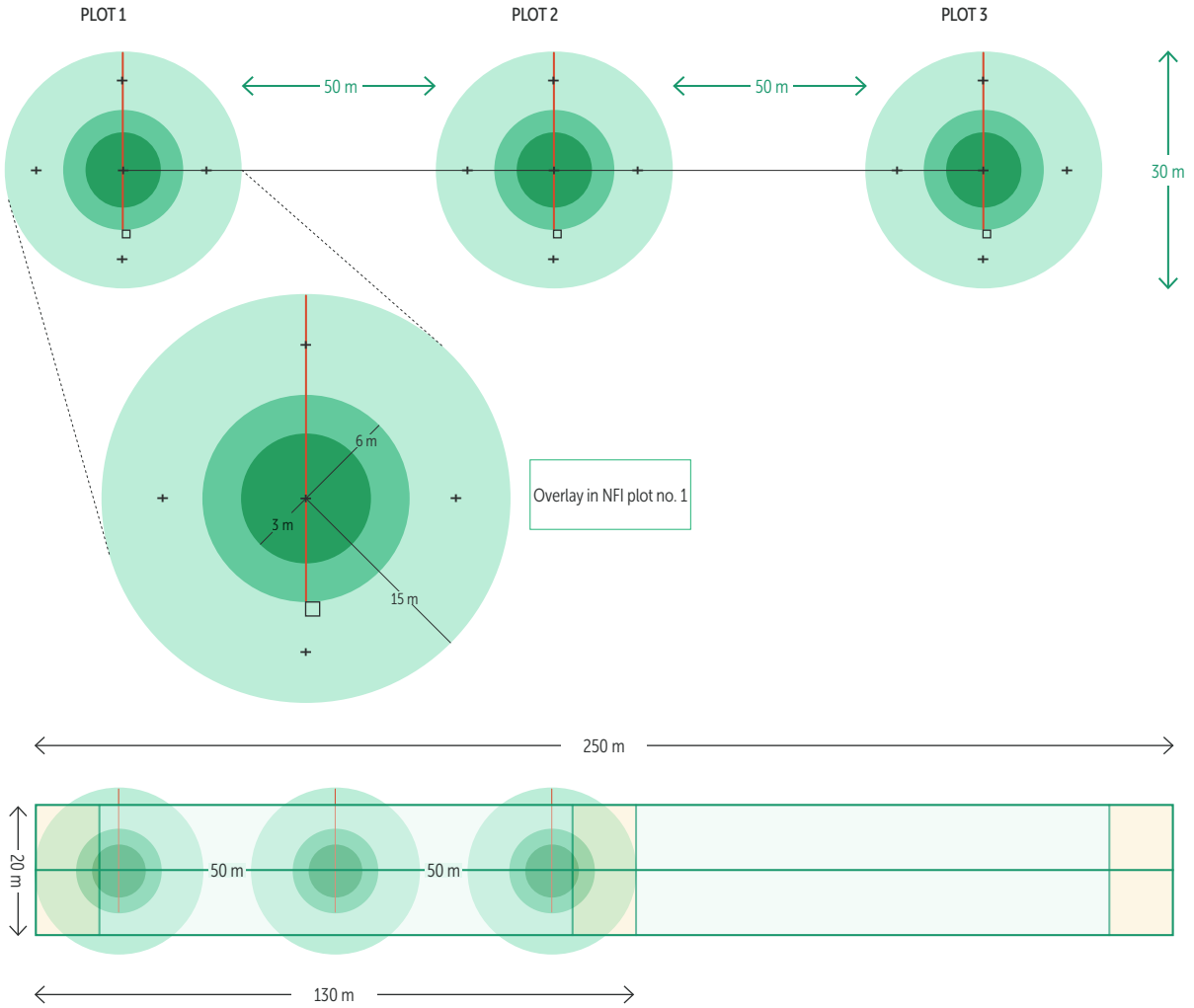
FIGURE 17.6

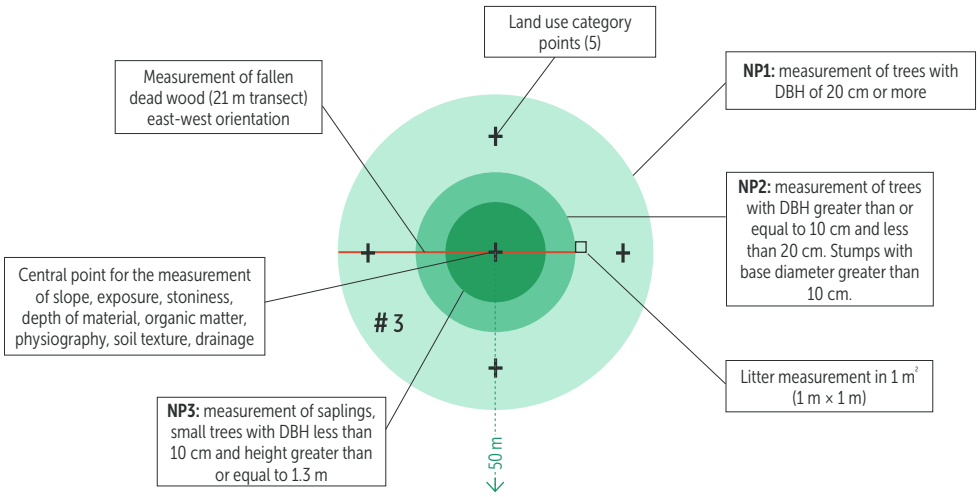
Design of sampling units and plots of the National Forest Inventory



Source: **ICF.** 2017b. Manual para la colecta de datos de campo para el Inventario Nacional Forestal de Honduras. Tegucigalpa.

FIGURE 17.7

Details of measurements at plot level



Source: **ICF.** 2017b. Manual para la colecta de datos de campo para el Inventario Nacional Forestal de Honduras. Tegucigalpa.

Table 17.4 provides a detailed description of the elements to be measured in the SU, specifying their shape, dimensions and area.

The location of the SUs in relation to the design of the previous cycles is shown in Figure 17.6.

The NFI consists of the assessment of a number of field variables (quantitative and qualitative) and subsequent calculations and analyses. Figure 17.7 describes the information collected at plot level.

17.5 LAND AREA, VOLUME AND BIOMASS CALCULATION

Honduras produces most of its official statistical information with data from the NFI, using a systematised process for the collection, processing and analysis of information. It has a central database with information from the three NFI measurement cycles, which is fed and updated monthly with the SU data collected by ICF technical staff. Field measurements are made with mobile devices that have installed the Silva Metricus software (Android version), which is designed for the collection of NFI variables (www.silvahn.com).

In this way, individual files are created for each SU and can be stored as SQL or Access databases. All field information is then unified, reviewed and refined to avoid gaps or anomalies in the data.

The desktop version of the Silva Metricus software is used for data processing and analysis, which generates different types of calculations from the updated central database. This database is associated with different allometric equations designed in specific studies for Honduras; likewise, regional equations are used to generate estimates that can be modified or updated, if necessary. The country has a protocol on methodologies and the use of equations for the calculation of NFI variables (ICF, 2016) and the software has user manuals for both versions.

The main calculations refer to volume, biomass and carbon dioxide, which are carried out for above-ground biomass, below-ground biomass, stumps, lying dead wood and litter, as appropriate. The land areas of different types of land cover, fire and pest damage, phytosanitary conditions, natural and anthropogenic disturbances, among others, are also calculated. Table 17.5 provides the equations used for calculating volume and biomass.

TABLE 17.4

Elements to be measured in the plots of the sampling unit

Element to be measured	Plot shape and size	Quantity	Area per sampling unit
NP 1: trees with DBH ≥ 20 cm	Circular with 15 m radius	3 per SU	2 120.58 m^2
NP 2: trees with DBH ≥ 10 cm and DBH ≤ 20 cm and stumps ≥ 10 cm diameter at the base	Circular with 6 m radius	3 per SU	339.29 m^2
NP 3: regeneration, trees with DBH < 10 cm and over 1.3 m in height	Circular with 3 m radius	3 per SU	84.82 m^2
Land use category (LUC)	Five points per NP 1, one at the centre and four at 11.6 m from the centre point in the direction of the four cardinal points (north, east, south and west)	15 per SU	Each point represents 141.37 m^2 or 6.667% of the SU area
Leaf litter (1 m × 1 m)	Square plots measuring 1 m on each side	3 per SU	3 m^2
Lying dead wood ≥ 10 cm in diameter	21 m transect oriented east to west. The transect starts at 6 m from the centre point of NP 1 with an azimuth of 90 degrees and passing through the centre of NP 1	3 per SU	
Lying dead wood of ≥ 5 cm and ≤ 10 cm in diameter	First section (6 m) of the 21-metre transect oriented east to west. Located between the start of the transect and the centre of the plot	3 per SU	
Fire and pests	In the five LUC points (centre, north, east, south, west)	15 per SU	Each point represents 141.37 m^2 or 6.667% of the SU area

Notes: DBH: diameter at breast height; NP: nested plot; SU: sampling unit.
Source: **ICF.** 2017b. Manual para la colecta de datos de campo para el Inventario Nacional Forestal de Honduras. Tegucigalpa.

TABLE 17.5

Equations used for volume and biomass calculations

Variable	Equation	Reference
Total volume (m^3)	Coniferous $0.00002838 \times DBH^2 \times H - 0.00002308 \times DBH^2 - 0.00635$	ACDI and COHDEFOR (1981)
	Ceiba pentandra $0.1416289196 + 4.36944 \times 10^{-5} \times (DBH^2 \times H) - 8.52212 \times 10^{-13} \times (DBH^2 \times H)^2$	
	Pouteria izabelensis $2.64261 \times 10^{-5} (DBH^2 \times H)^{1.073486}$	
	Virola koschnyi $3.17367 \times 10^{-5} \times (DBH^2 \times H)^{1.028854521}$	
	Dialium guianense $3.99495 \times 10^{-5} \times (DBH^2 \times H)^{1.039256484}$	
	Brosimum alicastrum $4.40524 \times 10^{-5} \times (DBH^2 \times H)^{1.016876336}$	
	Swietenia macrophylla $4.44909 \times 10^{-5} \times (DBH^2 \times H)^{1.005447155}$	
	Vochysia hondurensis $5.06922 \times 10^{-5} \times (DBH^2 \times H)^{0.977371702}$	
	Quercus skinneri $5.13625 \times 10^{-5} \times (DBH^2 \times H)^{1.004972}$	
	Terminalia amazonia $5.6810 \times 10^{-5} \times (DBH^2 \times H)^{0.998463036}$	
	Calophyllum brasiliense $6.43242 \times 10^{-5} \times (DBH^2 \times H)^{0.968922585}$	
	Other species $0.1083372662 + 4.6499 \times 10^{-5} \times (DBH^2 \times H) - 3.78846 \times 10^{-12} \times (DBH^2 \times H)^2$ Where: *DBH:* diameter at breast height *H:* total height	
Stump volume (m^3)	$[((D1/100^2) + (D2/100^2)) / 2] \times (\pi/4) \times H$ Where: *D1*: diameter at stump base *D2*: diameter at stump tip π: pi *H*: stump height	Smalian Formula, cited in Ferreira (2005)
Lying dead wood volume (m^3)	$1.2337 / L \times D^2$ Where: *L*: transect length *D*: diameter	ICF (2016)

TABLE 17.5 (CONTINUED)

Variable	Equation	Reference
Above-ground biomass (t)	Coniferous species $(0.11264421 \times (DBH^2 \times H)^{0.85091168}) / 1000$	Alberto (2005)
	Broadleaved species $(0.0673 \times (\rho \times DBH^2 \times H)^{0,976}) / 1000$ Where: ρ: wood density DBH: diameter at breast height H: total height	Chave *et al.* (2014)
Below-ground biomass (t)	$e^{(-1.0587 + 0.8836 \times ln\,(ab))}$ Where: ab: above-ground biomass (dry weight)	Cairns *et al.* (1997)

Source: **Alberto, D.** 2005. *Acumulación y fijación de carbono en biomasa aérea de Pinus oocarpa en bosques naturales de Cabañas, La Paz.* Escuela Nacional de Ciencias Forestales. Thesis.; **Cairns, M.A., Brown, S., Helmer, E.H. & Baumgardner G.A.** 1997. Root biomass allocation in the world's upland forests. *Oecologia*, 111: 1–11.; **Chave, J., Réjou-Méchain, M., Búrquez, A., Chidumayo, E., Colgan, M.S., Delitti, W.B.C., Duque, A.**, *et al.* 2014. Improved allometric models to estimate the aboveground biomass of tropical trees. *Global Change Biology*, 20(10): 3177–3190.; **CIDA (Canadian International Development Agency) & COHDEFOR (Honduran Forestry Development Corporation).** 1981. *Normas Técnicas de Inventario Forestal Nacional (INFONAC).* Proyecto Inventario Forestal Nacional – Macizo Central. Tegucigalpa, CIDA-COHDEFOR Forestry Programme.; **Ferreira, O.** 2005. *Manual de Dasometría.* Siguatepeque, Honduras, Escuela Nacional de Ciencias Forestales.; **ICF.** 2016. *Procedimientos de cálculos en la base de datos INF de Honduras*. REDD+ Project Honduras. Tegucigalpa.

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17.6 RESULTS OF THE NATIONAL FOREST INVENTORY OF HONDURAS

Honduras is currently in its third NFI measurement cycle. In accordance with the annual survey methodology (20 percent of the SUs per year), field activities will continue to be carried out to complete the planned measurement cycle by the end of 2021. This publication includes the results of the second measurement cycle (2011–2015), whose calculations were based on land area, volume and biomass, according to the land cover types included in the NFI (ICF, 2017a). The land area values included here consist of estimates made from field data. However, it should be clarified that the official land area data for the country are those generated from the Forest and Land Cover Map of Honduras. However, both types of data are important to make comparisons, suggestions and validations of the official figures. In alignment with the FRA 2000 classification, the NFI results are provided in Table 17.6, where 49.5 percent of the national territory belongs to the category of forest; furthermore, 16.3 percent falls under the category of other wooded land, 32.4 percent belongs to the other land category and approximately 1.8 percent of the territory consists of water bodies.

TABLE 17.6

Results of the second cycle of the National Forest Inventory of Honduras (2011–2015)

Variable	Result	Sampling error (%)[1]	Description
Land area (ha)	607 597.1	50.23%	Dry forest
	2 549 791.5	18.78%	Evergreen broadleaved forest
	1 714 808.9	27.07%	Coniferous forest
	616 849.2	36.03%	Mixed forest
	81 253.1	195.42%	Mangrove forest
	1 830 714.8	18.55%	Other wooded land
	3 644 637.4	15.42%	Other land
	203 548.0	63.22%	Inland water bodies
	11 249 200.0		**Total**
Volume (m^3)	98.7	47.24%	Dry forest
	292.6	20.63%	Evergreen broadleaved forest
	97.3	22.72%	Coniferous forest
	119.9	33.93%	Mixed forest
	324.6	192.66%	Mangrove forest
	39.2	27.62%	Other wooded land
	18.1	34.50%	Other land
	0.0	0.00%	Inland water bodies
	111.8	13.06%	**Average**
Biomass (t/ha)	55.2	26.22%	Dry forest
	182.9	23.91%	Evergreen broadleaved forest
	102.6	22.12%	Coniferous forest
	96.0	34.40%	Mixed forest
	281.4	0.00%	Mangrove forest
	11.0	28.57%	Other wooded land
	23.3	37.09%	Other land
	0.0	192.70%	Inland water bodies
	76.7	18.84%	**Average**

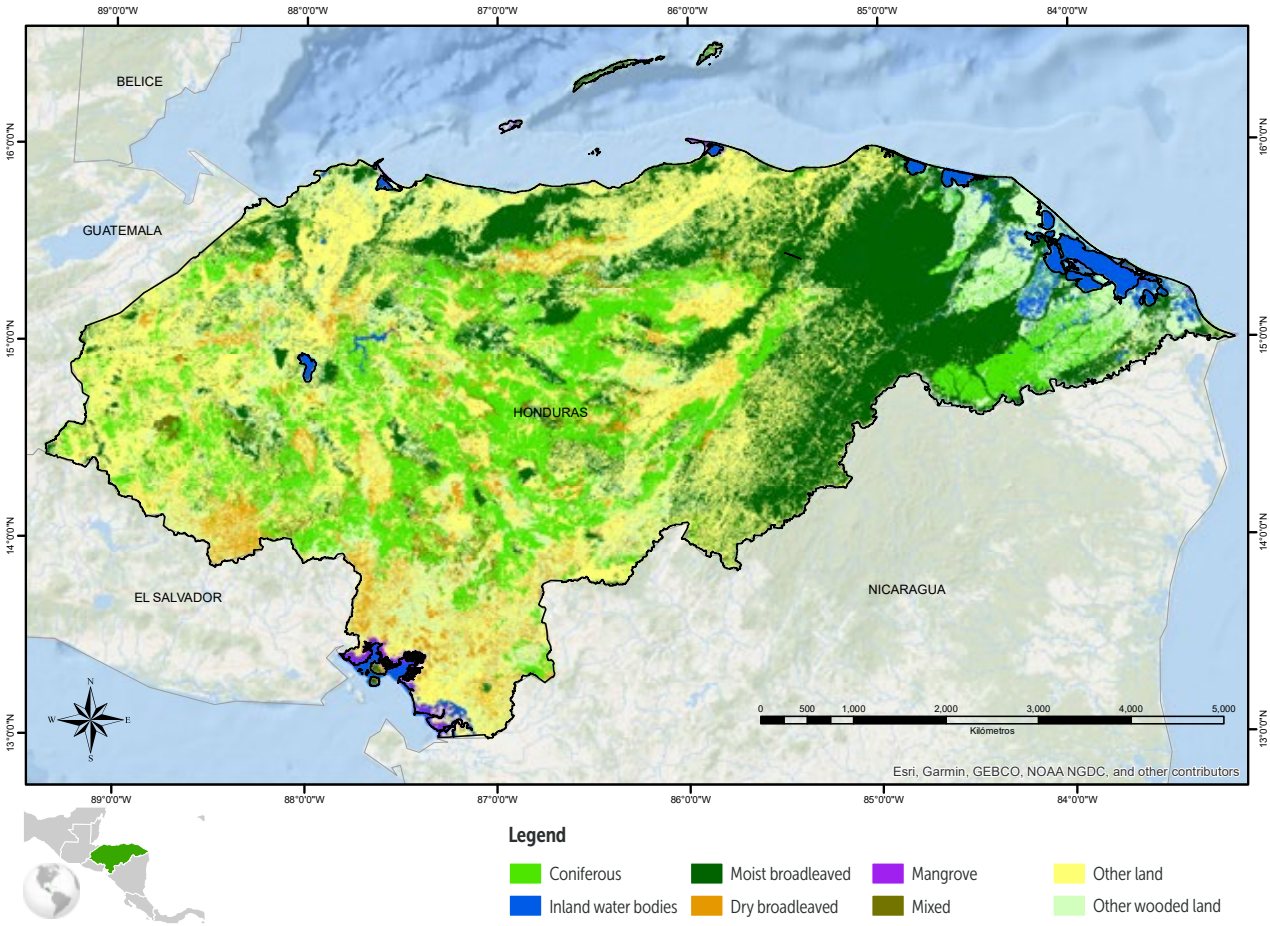
Note: [1] 95% confidence level.
Source: **ICF**. 2017a. Resultados de la Evaluación Nacional Forestal de Honduras. Tegucigalpa, Proyecto de Modernización del Sector Forestal de Honduras (EuroFor MOSEF).

In terms of volume, the results describe the estimates made for the above-ground forest biomass. It is estimated that 94.2 percent of the volume falls under the forest category; 4.0 percent of the volume belongs to the other wooded land category, and 1.8 percent of the country's average volume is in the other land category. It is estimated that Honduras has an average volume of 111.8 m³/ha, considering all land cover types. The biomass values describe the total estimate of this variable, considering the five carbon pools assessed by the NFI: above-ground biomass, below-ground biomass, stumps, lying dead wood and leaf litter. It is estimated that 95.4 percent of the biomass is found in the forest category; 1.5 percent of the biomass belongs to the category of the other wooded land, and 3.1 percent of the country's average biomass can be found in the other land category. All in all, it is estimated that Honduras has an average biomass of 76.6 tonnes per hectare, taking into account all types of land cover. Table 17.6 provides a detailed description of these values.

The land cover categories assessed by the NFI are based on the FRA 2000 classification. Figure 17.8 shows these categories based on the 2014 Forest and Land Cover Map of Honduras (ICF, 2014b), adapting the classification used by NFI.

FIGURE 17.8

National map of forest type distribution



The boundaries shown and the names and designations used on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any countries, territories, cities, areas, authorities, or delimitation of their frontiers or boundaries. Dotted lines on maps represent approximate boundaries for which there may not yet be full agreement.

Source: Prepared by the authors.

17.7 IMPLEMENTATION AND QUALITY CONTROL

Two stages for quality control were developed in the second measurement cycle. First, an external company, UNIQUE Forestry and Land Use GmbH, was hired to conduct field checks on 10 percent of the SUs surveyed. A methodological document was prepared (Wenzel, 2016) to carry out the entire quality control process, explaining each of the steps in detail. Essentially, the main activities of the quality control consisted of field checks and verifications to ensure that the data collection methodology was carried out in accordance with the field manual, and that the measurements and observations were correct and consistent with the reality in the field.

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Moreover, ICF staff working on the NFI carried out an additional quality control process in another 10 percent of the SUs. Thus, taking into account both the external and internal assessments, quality control was carried out in 20 percent of the SUs, which is deemed adequate considering that the fieldwork was carried out across the country.

For the third cycle, the same quality control methodology has been applied to 20 percent of the SUs. However, the process was carried out exclusively by ICF technical staff, following a strategy of staff deployment to other ICF forest regions; that is, once the field surveys were completed in one area, the forestry technicians moved to another area of the country to verify the measurements made by other field technicians. The general objective of the quality control process is to guarantee the accuracy, reliability and professionalism in the implementation of the NFI, thus contributing to providing national and local governments with a support tool for decision-making and for sustainable forest planning and management.

17.8 OTHER VARIABLES COLLECTED

The NFI methodology includes the collection of several variables in order to conduct general and specific calculations of these variables. In general, the following information is collected:

- general information on the SU: location, field crew and description of access;
- socioeconomic aspects of the (nearest) village: name, ethnic group, population, productive activities, population dynamics, history and available services;
- plot data: dates, times, coordinates, sketches, relation to previous SUs and reference points;
- land use class: origin of forest, land tenure;
- relevant data: canopy cover, shrub cover, relationship to protected areas, relationship to micro-watersheds, relationship to forest management plans and use designation;
- trees (NP 1 and NP 2): botanical sample collection, azimuth (from plot centre), stem quality;
- soil data: slope, exposure, depth, organic matter, physiography, texture and drainage.

17.9 FUTURE PROSPECTS

Honduras is developing its NFI through a process of continuous improvement, with the aim of maintaining a reliable measurement system that complies with quality and accuracy standards. The main future action proposed is to finish the third measurement cycle scheduled for the year 2021, producing a country document with results that illustrate the state and dynamics of the ecosystems in Honduras. In addition, activities regarding the fourth cycle are expected to start once the activities of the current measurement cycle have been completed.

One of the NFI's areas for improvement has been to increase the sampling intensity in mangrove forests, considering that few samples were available in these strata. During 2017, 2018 and 2019, new SUs were established including soil sampling to determine the amount of carbon stock. In late 2020, the first country document on the assessment of mangrove ecosystems at the national level was finalised, which will be distributed officially in 2021.

In 2020, a stratified inventory was also carried out in the areas affected by the pine beetle (*Dendroctonus frontalis*). It should be noted that between 2013 and 2016, Honduras was severely affected by this forest pest in an area of more than 500 000 hectares. The purpose of the inventory was to quantify the impacts in terms of carbon content and volume, as well as to assess the natural regeneration and the state of the plantations. Based on the results, restoration and conservation areas have been defined and the recovery time of the affected area has been estimated.

Other planned activities include the development of a soil sampling methodology for all ecosystems in the country (currently in draft form), based on the successful experience in mangrove ecosystems. The main purpose will be to report on soil carbon content, as there is no official information on these concentrations per ecosystem type.

One of the goals of the NFI is to have a relational database management system that enables data storage, access and structuring, taking advantage of free alternatives such as Microsoft SQL Server. The aim is to migrate the NFI data to this system. Among the advantages is the higher level of security in managing access permits, as well as the possibility of working through local networks and accessing other available software, such as those developed for business intelligence.

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Chapter 18

JAMAICA

TOWARDS THE NATIONAL FOREST INVENTORY OF JAMAICA

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18.1 HISTORICAL OVERVIEW OF NATIONAL FOREST INVENTORIES

The first National Forest Inventory (NFI) of Jamaica commenced in 1998 using sample-based remotely sensed data and detailed biophysical inventory data. The assessment was reported in 2003. The scale of this inventory was at the watershed management unit (WMU) level, which is more closely aligned to ecological parameters and contains forest reserves within its boundaries. The Trees for Tomorrow Project and the Forestry Department technical staff decided to use the detailed biophysical inventory data collected in the WMUs and within the Forest Reserves (FR) since 1998 to estimate the island-wide forest characteristics (Forestry Department/Trees for Tomorrow, 1999). These data were supplemented with the broad forest type areas determined by 1998 Landsat satellite imagery interpretation. The data from existing permanent research plots in the Blue Mountains collected by the University of the West Indies and other universities were used to verify some inventory results (Healey, 1990). This approach was further supported by inventories of Buff Bay/Pencar WMU, Rio Minho WMU and Martha Brae WMU (including the entire Cockpit Country FR). In addition, data were collected in the inventories of the Dolphin Head FR, the Black River and Negril morass, which cover most forest types found in Jamaica. Between 1998 and 2000, an extrapolation approach was applied to produce an assessment for the entire island due to resource constraints within the Forestry Department and the urgent need for biophysical inventory data to support several overlapping environmental projects in the abovementioned watersheds.

After the 2003 National Forest Inventory report, the subsequent forest inventories focused on the Forest Management Unit (FMU) level. Forest Management Units are administrative boundaries that group Forest Estates in similar geographic locations and proximities to better manage resource allocations. Forest inventories conducted in FMUs satisfied several operational obligations, such as providing data for Local Forest Management Plans, harvesting plans, and other projects and programmes targeting forest reserves within FMUs. The Forestry Department produced Biophysical Inventory (BPI) reports for Forest Estates within six FMUs between 2014 and 2019. The inventory methodology conducted at the FMU level included collecting field data (for instance, tree species, diameter at breast height [DBH], soil texture, fauna, etc.) and the processing and mapping of collected data by forest land use/cover type. However, the current BPI application where plot data are stored is not scalable. The Microsoft Access platform on which this application is built restricts the amount of plot data it can hold. In addition, this BPI methodology only provides information on physical resources of FMUs. Forest resources on private and other government-owned land parcels are not recorded. Lastly, the current BPI approach does not include all carbon stock data.

TABLE 18.1

Historical description of forest inventories in Jamaica

Inventory cycle	Execution period	Level	Sampling design	Number of sampling units
NFI	1998–2003	National	Transect line with 20 m × 25 m plots	525
FMU 6	2014–2015	Subnational	Transect line with 20 m × 25 m plots	~95
FMU 5	2015–2016	Subnational	Transect line with 20 m × 25 m plots	235
FMU 4	2016–2017	Subnational	Transect line with 20 m × 25 m plots	225
FMU 2 & 3	2017–2018	Subnational	Transect line with 20 m × 25 m plots	162
FMU 18	2018–2019	Subnational	Transect line with 20 m × 25 m plots	181

Note: FMU: Forest Management Unit; NFI: National Forest Inventory.
Source: Prepared by the authors

In 2018, 181 temporary sampling units (SU) were established in the ten parcels of Forest Estate that comprised FMU number 18. The SUs were determined by calculating the allowable error at 10 percent, with a 95 percent confidence interval and 5 percent for the watershed, resulting in 150 to 175 SUs. The sampling design was a random stratified sample approach. The final number of SU was determined by the forest types and the size of each Forest Estate in FMU 18. Cumulatively, 181 SUs were established across all Forest Estates with all parcels and forest types being sampled.

Quadrants measuring 25 metres (m) by 20 m (0.05 hectares [ha]) were established along a transect line with plot centimetres 100 m apart. Within this 25 m by 20 m plot, the DBH for all trees with DBH greater than 10 centimetres (cm) was measured. A more detailed assessment was conducted on three trees each from the following diameter classes: DBH of 10 cm to 20 cm; 20 cm to 30 cm; and greater than 30 cm. Within the plot, a subplot was constructed measuring 10 m by 5 m (0.005 ha). All saplings over 2 m in height but under 10 cm DBH were counted. A regeneration plot was constructed, measuring 2 m by 1 m (0.0002 ha), where all seedlings under 2 m in height were counted and recorded.

In 2019, the Forestry Department decided that an update of the NFI was required given the need to facilitate better decision-making towards sustainable forest management. These initiatives include providing a more expansive inventory perspective to inform Forestry Department projects or programmes related to the Forest Sector Plan (Forestry Department, 2017). This approach would require expanding inventory activities to provide information at national level to other natural resource management stakeholders. Against this background, the new NFI will have three significant objectives. The revised approach will standardize field procedures consistent with collecting and assessing forest resources across Jamaica. It will also provide a scalable platform that changes in response to legislation and new customer demands without changing the core requirements. Lastly, this new approach will analyse the present and prospective conditions and provisions of forest and other lands island-wide.

An overview of the forest inventories implemented to date in Jamaica is provided in Table 18.1.

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TABLE 18.2

Summary of definitions for forest, volume and biomass

Term	Definition	Variables and thresholds
Forest	Land with tree crown cover (or equivalent stocking level) of more than 75% on an area of more than 2.25 hectares	Area ≥ 2.25 ha Crown cover > 75%
Volume	The amount of merchantable wood present in a tree or group of trees in an area	Diameter at breast height (DBH): 25 cm or greater for Caribbean pine DBH: 20 cm or greater for all other species Stem top > 10 cm
Biomass	The volume of the entire tree above the ground and below ground to include branches, leaves and roots Down woody debris Litter (leaves, needles, twigs, cones, detached bark, dead lichen, dead moss, and herbaceous stems and flower parts) Duff (decomposition of plants and animals deposited on top of an organic or mineral surface)	DBH: 10 cm or greater Coarse woody debris (CWD) diameter > 7.6 cm Fine woody debris (FWD) diameter: 0 cm to 7.6 cm Twigs (diameter < 0.6 cm)

Source: **FAO**. 1998. FRA 2000: Terms and definitions. Forest Resources Assessment Working Paper 1. Rome, FAO.; **Forestry Department**. 1999. Land use/cover types areas 1989 and 1998 per watershed management unit and protection status. Trees for Tomorrow technical Report. Kingston.

18.2 TERMS AND DEFINITIONS

The following section explains the terms and definitions used by the Forestry Department. A summary is provided in Table 18.2.

Forest: Land with tree crown cover (or equivalent stocking level) of more than 75 percent on an area of more than 2.25 hectares with a combined cover of shrubs, bushes and trees and absent of other predominant land uses different from forest (Forestry Department, 2015).

Explanatory notes

- The definition includes forest roads, firebreaks and other small open areas; forest in national parks, nature reserves and other protected areas such as specific environmental, scientific, historical, cultural or spiritual interest.
- It excludes areas covered with bamboo (*Bambusa vulgaris*). Bamboo areas are categorised under "other land".
- It includes elfin forest of the Blue Mountains. Elfin forest consists of a canopy that is less than 5 m tall and is stunted and gnarled due to the area's high elevation.
- It includes short open-dry forest in semi-arid environments. Open scrubs, shrubs, bush or brushland with trees or shrubs 1 m to 5 m tall and crowns not in contact, in drier parts of Jamaica with indicator species such as *Prosopis juliflora* (cashaw) or *Stenocereus hystrix* (columnar cactus).
- Includes abandoned cultivation lands with the natural regeneration of trees.
- Includes areas with mangroves in tidal zones, regardless if the area is classified as land area or not.

Other wooded land: This definition is not used in the NFI of Jamaica; it is only used for reports to the Food and Agriculture Organization of the United Nations (FAO).

Other land: This definition is not used in the NFI of Jamaica and is only used for FAO reports.

Volume: The amount of merchantable wood present in a tree or group of trees in an area. It is measured in cubic metres or cubic feet. Volume is only calculated for trees with a DBH of 20 cm or greater (for Caribbean pine, greater than 25 cm). Includes the stem from the stump level to the merchantable top.

Explanatory notes

- Volume is estimated by measuring the tree's DBH (1.3 m above the ground) against the merchantable height of the tree.
- Merchantable height is the distance between the stump and merchantable top.

- Merchantable top refers to the section of the main stem of the tree with a diameter of 10 cm or where there is a major branch/fork or bend.
- Diameter at breast height refers to diameter over bark.
- Stump level is usually 30 cm above the ground (or higher for trees with buttress roots)
- It excludes branches, twigs, foliage, flowers, seeds and roots.

Biomass: The volume of the entire tree (DBH of 10 cm or wider) above the ground and below ground to include branches, leaves and roots. It also includes down woody debris, litter and duff; see Table 18.2 for more details.

Explanatory notes

- This definition is based on the United States Department of Agriculture (USDA) Forest Service's definition for biomass and is currently under revision.
- It is measured in tonnes per hectare and excludes organic matter below the soil.
- It includes leaf litter, duff and deadwood, as well as saplings and regens.

The Forestry Department has several definitions for forest types found on the island. These definitions are summarised in Table 18.3.

TABLE 18.3

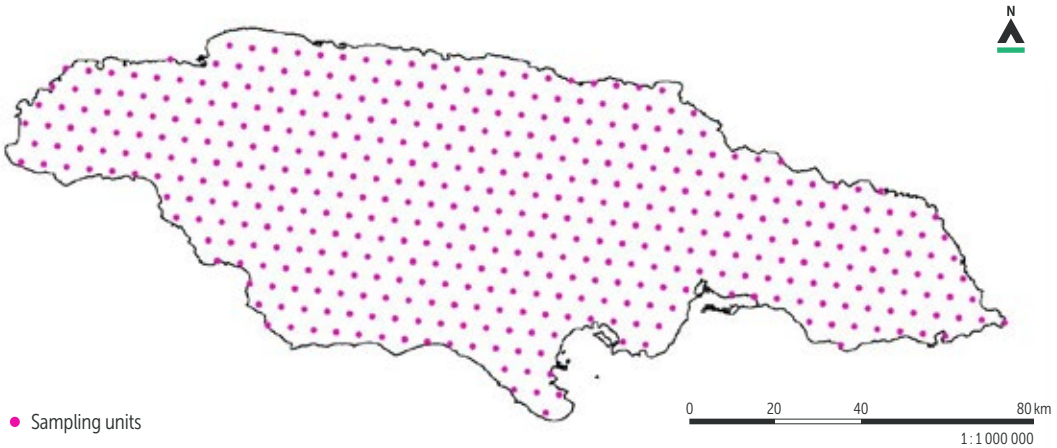
Summary of definitions for different forest types

Term	Definition	Variables and thresholds
Closed broadleaved	Forest cover consisting of broadleaf trees at least at least 5 m tall and crowns interlocking with minimal human disturbance. This is as close to primary forest as can be found in Jamaica.	Height ≥ 5 m
Disturbed broadleaved	Forest with broadleaf tress at least 5 m tall and indicator species of disturbance such as *Cecropia peltata* (trumpet tree). This category has less than 15% disturbance.	Height ≥ 5 m Disturbance < 15%
Tall open dry	Open natural woodland or forest with trees at least 5 m tall and crown not in contact in drier parts of Jamaica with indicator species such as *Metopium brownii* (burn wood) and *Bursera simaruba* (red birch).	Height ≥ 5 m
Short open dry	Open scrubs, shrubs, bush or brushland with trees or shrubs 1 m to 5 m tall and crowns not in contact in drier parts of Jamaica with indicator species such as *Prosopis juliflora* (cashaw) or *Stenocereus hystrix* (columnar cactus).	Height: 1 m to 5 m
Swamp	Edaphic forest (waterlogged soils) with a single tree storey with indicator species such as *Symphonia globulifera* (hog doctor) and *Roystonea princeps* (royal palm).	Altura: 1 m a 5 m
Mangrove	Edaphic forest (areas with brackish water) composed of trees with stilt roots or pneumatophores with indicator species such as *Rhizophora mangle* (red mangrove).	
Secondary forest	New classification identified (2013) having broadleaf forest equal or greater than 75% with disturbance levels between 10% and 25%. This level of disturbance distinguishes it from disturbed broadleaf forest.	Height ≥ 5 m Disturbance: 10% to 25%
Plantation forest	Forest cover re-established by reforestation or natural regeneration consisting of hardwood species such as mahogany and mahoe, and softwoods such as Caribbean pine.	
Bamboo	Area covered with over 75% *Bambusa vulgaris* on over 2.25 ha of land.	Bamboo cover > 75%

Source: **Forestry Department.** 2015. *Jamaica's Land Use Cover Assessment: A comparative assessment of forest change between 1998 and 2013.* Kingston.

FIGURE 18.1

Jamaica National Forest Inventory sampling grid



The boundaries shown and the names and designations used on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any countries, territories, cities, areas, authorities, or delimitation of their frontiers or boundaries. Dotted lines on maps represent approximate boundaries for which there may not yet be full agreement.

Source: Prepared by the authors.

18.3 SAMPLING DESIGN

18.3.1. NATIONAL FOREST INVENTORY BASE GRID

The Jamaica NFI will be done using a systematic sampling grid of 458 permanent sampling points spread equidistant across the island (Figure 18.1), with 198 (43 percent) falling in forest cover at the time the sampling grid was first generated. The remaining 260 sampling units (57 percent) are categorised as "other land" (Table 18.4). Theoretically, one SU represents 2 403 ha and are located at a distance of 5 267 m from each other. The data gathered from the NFI will be used to calculate biomass and carbon stock, among other variables, and will be scaled to represent the country's ecological status.

Considering the other obligations of the Forest Resource Assessment Unit, the unit will complete approximately 20 percent of the total SUs each year. This will require an estimated four months annually to complete. As a result, it will take five years for the NFI of the entire Island to be completed. Once the initial five-year cycle is completed, the inventory team will repeat the assessment of the SU from the initial 20 percent that was assessed in year 1.

TABLE 18.4

Characteristics of the National Forest Inventory sampling design

Country	Total area (1 000 ha)	Total number of sampling units			Total number of sampling units
		Forest	Other wooded land	Other land	
Jamaica	1 094	198	0	260	458

Source: Prepared by the authors.

18.3.2. NATIONAL FOREST INVENTORY FOREST MANAGEMENT UNIT INTENSIFICATION

A greater level of detail of the Forest Estates' biophysical status is required by the Forestry Department to properly manage the over 250 parcels of Forest Estates, Crown Lands and FMUs. Hence, there is a need to increase the sampling intensity to reflect the land cover composition of Forest Estates more accurately.

As a result, a stratification system was developed to allow varying areas of Forest Estates to be adequately sampled. This stratification will allow selected Forest Estates (grouped into FMUs) to be assessed annually. Overall, there are 1 342 sampling units spread over the Forest Estates that the Forestry Department manages (see Figure 18.2); some of these plots overlap with the NFI sampling units

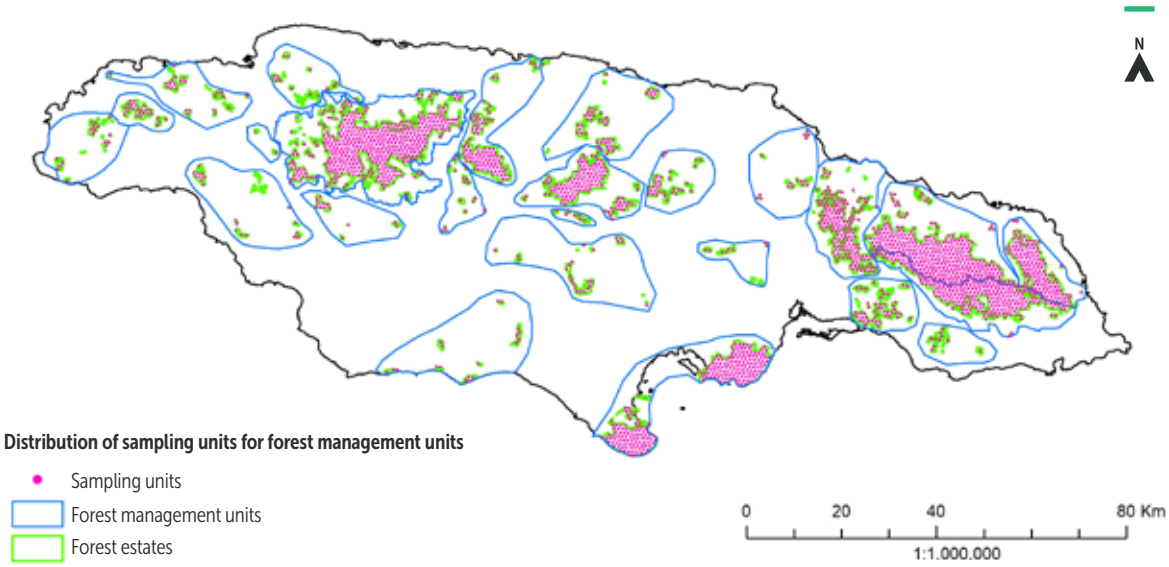
mentioned above. Each year, the Forest Resource Assessment Unit will seek to conduct an inventory of approximately 10 percent of the Forest Estates and, subsequently, 10 percent of the FMUs. This operation is estimated to last an additional six months each year. Hence, it will take a period of ten years for all of the FMUs to be assessed.

Using the grid sampling add-in for ESRI ArcMap submitted to the Forestry Department by the USDA Forest Service team, three different NFI sampling grid intensities (84 times, 36 times and 12 times the NFI sampling intensity described above) were generated and proposed based on each Forest Estate's size (Table 18.5).

A total of 440 sampling units at an intensity of 84 times the NFI standard sampling intensity are proposed for 147 Forest Estates. These estates, measuring less than 150 ha, will use the highest sampling density and will have the sampling units at a distance of 575 m from each other. Theoretically, one sampling unit will represent 29 ha (one eighty-fourth times the base grid size of 2 403 ha). This high intensity is justified due to the increased fragmentation and small size of many Forest Estates across the island. Unfortunately, even at a sampling intensity of 84 times, over 40 of the smallest estates did not have a sampling unit. Hence, a buffer zone of 400 m was generated around estates measuring less than 20 ha.

FIGURE 18.2

Stratification and distribution of sampling units in Jamaican Forest Management Units



The boundaries shown and the names and designations used on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any countries, territories, cities, areas, authorities, or delimitation of their frontiers or boundaries. Dotted lines on maps represent approximate boundaries for which there may not yet be full agreement.

Source: Prepared by the authors.

TABLE 18.5

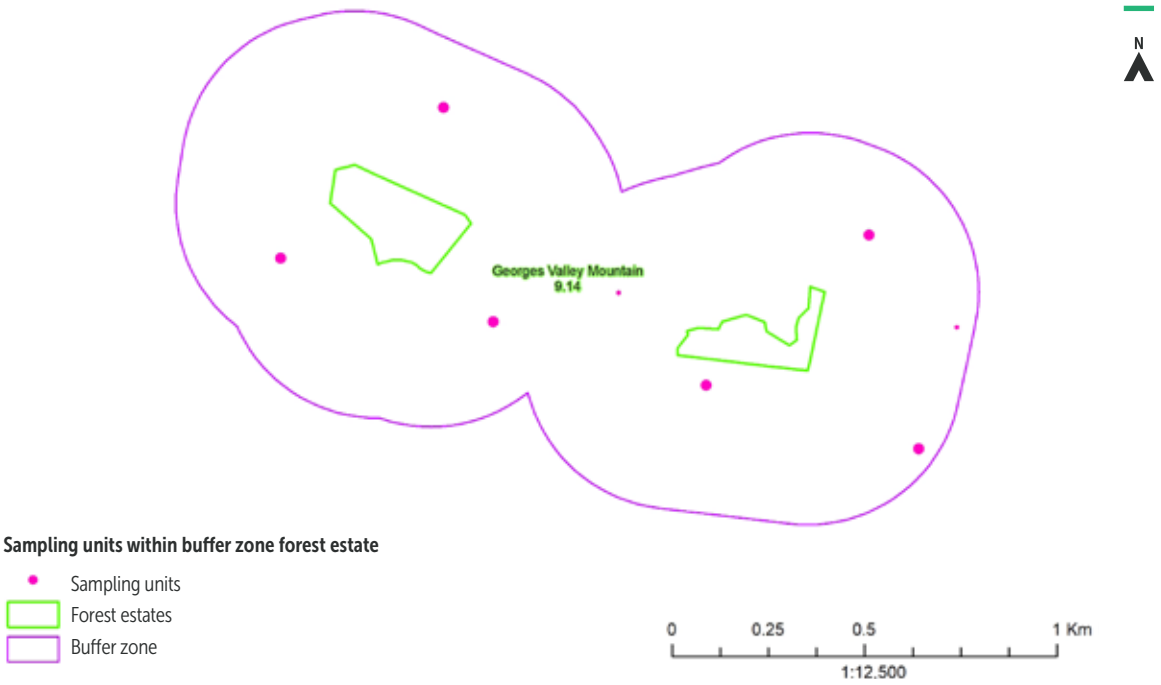
Intensification of the National Forest Inventory

Sampling grid intensity	Number of sampling units	Land area represented (ha)	Distance between sampling units (m)
84 times	440	29	575
36 times	416	67	878
12 times	486	200	1 521
1 time	198	2 403	5 267

Source: Prepared by the authors.

FIGURE 18.3

Buffer zone of Forest Estate which did not contain any sampling units



Source: Prepared by the authors.

Sampling units that fell within this buffer zone were assigned to the closest Forest Estate (Figure 18.3). Estates measuring less than 10 ha have a maximum of one plot to avoid oversampling of these small areas, while estates measuring between 10.01 ha and 20 ha have a maximum of two sampling units. A buffer of 100 m was also created for estates measuring between 20.01 ha and 100 ha. This approach is justified by the fact that ten estates within this range had zero sampling units in them. All sampling units within this buffer will be sampled.

The second frequency of sampling was proposed at 36 times the standard sampling intensity. This approach will be applied to estates measuring between 150.01 ha and 1 500 ha. At this frequency, SUs are at a distance of approximately 878 m from each other, with one SU theoretically representing 67 ha (one thirty-sixth times the base grid size of 2 403 ha). A total of 416 SUs units are to be completed at this intensity.

The third frequency of sampling was proposed at 12 times the standard sampling intensity. This technique will be applied to estates over 1 500 ha, with SUs at a distance of approximately 1 521 m from each other. Theoretically, one of these SUs represents 200 ha (one-twelfth times the base grid size of 2 403 ha). A total of 486 SUs are to be completed at this intensity.

A total of twenty-five FMUs make up the Forest Estates that the Forestry Department manages (Table 18.6). These FMUs encompass a total of 129 028 ha of land. Currently, 1 342 sampling units are being proposed to assess these Forest Estates.

TABLE 18.6

Total number of sampling units per Forest Management Unit

Forest Management Unit	Total area (1 000 ha)	Total number of sampling units
Portland Bight	14.629	82
Bull Head	0.294	11
Stephney – Johns Vale	8.059	62
Blue Mountain – Western	8.577	142
Orchard and environs	3.004	70
Windsor Castle	0.829	18
Blue Mountain – Southern	15.466	111
Blue Mountain – Eastern	8.444	66
Blue Mountain – Northern	19.395	123
Fort George and environs	0.506	16
Tulloch-Hampton Estates	0.547	11
Mt. Diablo	1.709	45
Ballintoy	2.750	47
Eastern Trelawny	6.403	62
Cockpit Country	29.323	235
North-Central St. James	0.770	18
Eastern Hanover	1.339	32
Dolphin Head	1.639	34
Western Westmoreland	0.876	22
South-Eastern Westmoreland	1.020	28
Croydon	0.114	7
St. James – St. Elizabeth	0.647	16
Gourie	0.411	30
Southern Manchester	1.052	25
Teak Pen	1.225	30
Total	**129.028**	**1 342**

Table 18.6 Source: Prepared by the authors.

18.4 DESIGN OF THE SAMPLING UNITS

The SU consists of a cluster of four plots (Figure 18.4). The centre plot is labelled Plot 1. Plot 2 is located 360° from Plot 1, Plot 3 is located 120° from Plot 1, and Plot 4 is located 240° from Plot 1, at a horizontal distance of 36.58 m. The area of the sampling unit (four plots) is approximately 674.48 m².

Diameter at breast height is taken using a DBH tape at 1.3 m from the ground for trees with DBH 10 cm or greater. The height and DBH of live trees, standing dead trees and stumps are taken in the four plots.

From the centre of the plot, heading 90° at a horizontal distance of 3.66 m, a transect line is drawn to the centre of the plot (Figure 18.5). The plot has a radius of 2.07 m. Within the plot, saplings – defined as trees with a DBH greater than or equal to 2 cm but less than 10 cm, and greater than 2 m in height – are identified and their diameter is recorded. Seedlings/regenerations – defined as plants less than 2 cm in diameter and above 30 cm in height – are also identified and counted.

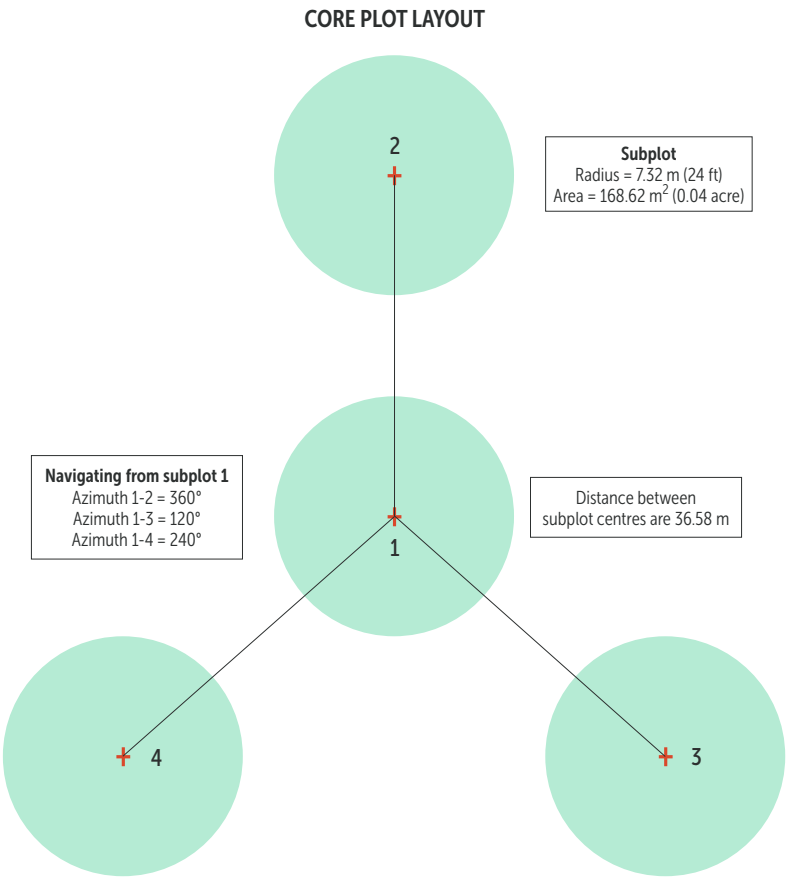
A planar transect, measuring 14.64 m, runs across the diameter of each plot. The diameter of down woody debris is measured along this transect. In each plot, the lines run in specific directions based on the plot number. Figure 18.6 illustrates the direction of each planar transect line.

Coarse woody debris (CWD) includes downed dead trees and shrub boles, large limbs and other woody pieces that are greater than 7.6 cm in diameter and severed from their original source of growth. It is measured along the transect line at the point where the transect line touches the debris (USDA Forest Service, 2018).

Fine woody debris (FWD) includes downed dead branches, twigs and small tree or shrub boles less than 7.6 cm in diameter that are not attached to a living or standing dead source. It is measured from 4.3 m to 6.1 m and 4.3 m to 7.3 m along the transect line, depending on the FWD class (see Table 18.7 for more details). Down woody debris is measured at the point of contact with the transect line. If the transect line makes contact with down woody debris multiple times, each point of contact is measured. The decomposition class (solid, medium, rotten) is also recorded (USDA Forest Service, 2018).

FIGURE 18.4

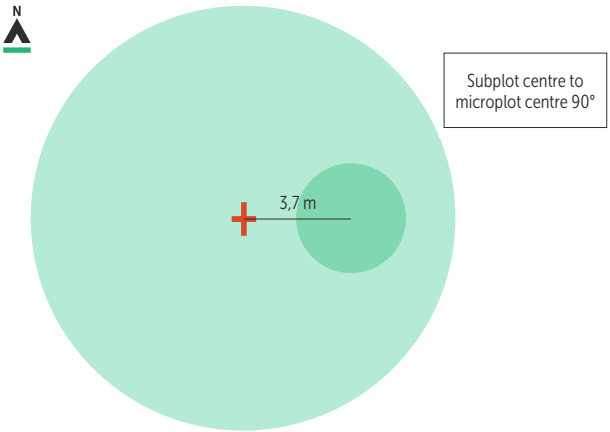
Sampling unit layout



Source: **USDA (United States Department of Agriculture) Forest Service.** 2018. *Forest Inventory and Analysis: National Core Field Guide. Vol. 1: Field data collection procedures for Phase 2 plots.* Washington, DC.

FIGURE 18.5

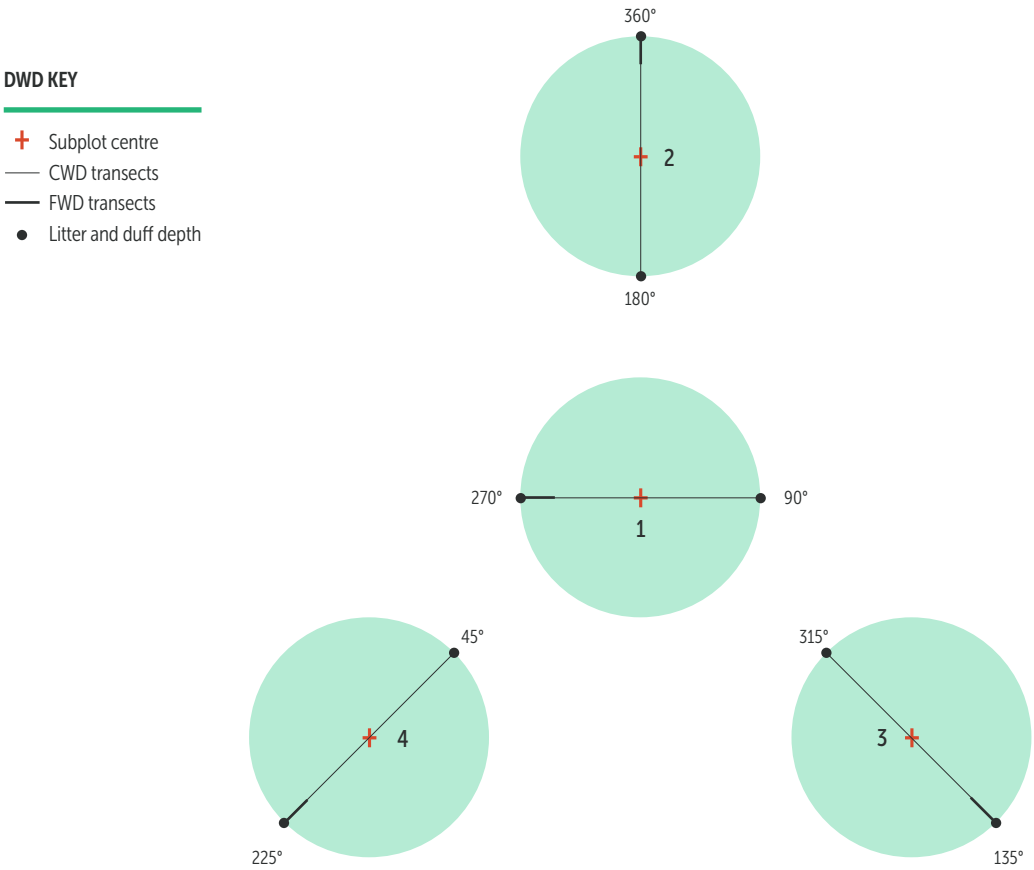
Plot layout



Source: **USDA Forest Service.** 2018. *Forest Inventory and Analysis: National Core Field Guide. Vol. 1: Field data collection procedures for Phase 2 plots.* Washington, DC.

FIGURE 18.6

Planar transect layout at each plot



Note: CWD: coarse woody debris; FWD: fine woody debris; DWD: down woody debris.
Source: **USDA Forest Service.** 2018. *Forest Inventory and Analysis: National Core Field Guide. Vol. 1: Field data collection procedures for Phase 2 plots.* Washington, DC.

TABLE 18.7

Categories for fine woody debris

Category of fine woody debris (FWD)	Size class	Diameter range (D)	Transect length (horizontal distance)	Transect location (horizontal distance)
Small FWD	1	0 cm ≥ D ≤ 0.90 cm	1.83 m	4.27 m to 6.10 m
Medium FWD	2	1.00 cm ≥ D ≤ 2.50 cm	1.83 m	4.27 m to 6.10 m
Large FWD	3	2.60 cm ≥ D ≤ 7.60 cm	3.05 m	4.27 m to 7.32 m

Source: Prepared by the authors.

TABLE 18.8

Equations used for volume and biomass/carbon calculations

Variables	Equation	Reference
Total volume (m^3) softwood	$1 - e^{1.0998 + (-0.82175 \times (+DBH - 16)^{0.5})} \times 0.0000192 \times DBH^{1.894} \times Height^{1.203}$	Forestry Department/Trees for Tomorrow (1999)
Total volume (m^3) hardwood	$\dfrac{\dfrac{DBH^2}{4} \times Height \times Form\ factor \times \pi}{10\,000}$	Forestry Department/Trees for Tomorrow (1999)
	Where: *DBH:* diameter at breast height	
Biomass (kg)	n/a	

Source: **Forestry Department/Trees for Tomorrow.** 1999. *Land use/cover types areas 1989 and 1998 per watershed management unit and protection status.* Technical Report. Kingston.

18.5 CALCULATION OF VOLUME

Two equations are used to calculate volumes in Jamaica; the first formula is used for Caribbean pine (*Pinus caribaea*). A second formula is used to measure all other hardwood species (see Table 18.8). Depending on the species, however, a different form factor is applied (see Table 18.9). Volume data is calculated using Microsoft Excel.

Biomass was not previously calculated; however, it will be calculated in future inventories. The equation to be adopted has not yet been finalised.

TABLE 18.9

Form factors used to calculate the volume of hardwood species

Species	Form factors
Mahoe	0.59
Broadleaf	0.62
Santa Maria	0.63
Honduras mahogany	0.53
Teak	0.63
Eucalyptus	0.57
Other	0.70

Source: Prepared by the authors.

18.6 RESULTS OF FOREST INVENTORY IN FOREST MANAGEMENT UNIT 18

Following the completion of the first NFI in 2003, inventories have been conducted within the FMUs. The results presented here are from the last FMU inventory conducted in Jamaica, which was completed in 2019. The survey of the NFI, using the new methodology adopted from the USDA Forest Service, will start at the end of 2021.

The most recent inventory was conducted in 2018–2019 in FMU 18 (Dolphin Head), located in western Jamaica. This inventory assessed a cumulative total of 1 639.23 ha for nine Forest Estates managed by Jamaica's Forestry Department. The data collected from this assessment have been used to inform the Forestry Department's operational and strategic Forest Estate management plans and silviculture plans, along with projects or programmes that will take place in these specific Forest Estates.

Plot data was entered into a Microsoft Excel platform to conduct data analysis and generate the relevant reports required for the assessment. The primary variables recorded in the inventory were the frequency of species, stems per hectare per species, basal area, species richness, and evenness and diversity indices.

The 2018 assessment of the Dolphin Head Mountains Area correlated with findings by Camirand (2002) to show that soil type plays a role in the distribution, composition, diversity and growth of Jamaican forests. The findings also reveal that the species distribution and dominance show the level of disturbance and adaptability of a forest stand. Additionally, access to forest stands which are on hilltops will determine their level of disturbance. There is much variability in the vegetation and species composition of the Forest Estates regardless of proximity. Overall, the findings suggest that a monitoring framework to manage the level of disturbance within the FMU is needed. This activity would specify the efforts needed to enhance the diversity and quality of vegetation cover within the Dolphin Head FMU.

Volume was not calculated as it is only calculated in areas that contain lumber tree plantations, and no lumber tree plantations exist in this area. Biomass and carbon were not assessed as part of the former inventory methodology.

18.7 IMPLEMENTATION AND QUALITY CONTROL

A new methodology is currently being developed for Jamaica's NFI programme. As such, all the details of quality assurance have not yet been finalised. The revised NFI programme will be governed by a Quality Assurance (QA) policy, which is currently in a working document phase. This document will contain procedures and methodologies designed to mitigate and correct errors in the NFI programme. These procedures will include:

- structured training for field crews and QA crews before engaging in field data collection;
- dendrology training for field crews and QA crews;

- adoption of the USDA Forest Service's Mobile Integrated Data Acquisition System (MIDAS) platform (USDA Forest Service, 2021). This programme has built-in logic checks and value range limitation.

The Forestry Department will promote a gender distribution of 50 percent men and 50 percent women in its activities.

In addition, the Forestry Department will incorporate satellite imagery and other remotely sensed data to supplement field data analysis. The recent acquisition of two unmanned aerial vehicle units will facilitate the assessment of inaccessible areas in the Blue Mountains and Cockpit Country, the island's largest forest blocks.

18.8 FUTURE PROSPECTS

The NFI of Jamaica will be conducted over five years (2021–2024) by the country's Forestry Department. This assessment is the first forest inventory using permanent sample plots systematically distributed across Jamaica.

Jamaica's forest cover categories are increasingly undergoing significant land use changes due to several drivers of deforestation, such as agriculture, expansion of housing developments and increased investment in tourism infrastructure. The new NFI will provide island-wide baseline data/information to allow for informed decisions to promote more sustainable management of national forest resources.

Several milestones need to be achieved in order to start the programme, including the following:

- training of field crews to collect forestry inventory data;
- training of Forest Inventory Analysis (FIA) team to interpret data and generate reports;
- installation and activation of the modified USDA Forest Service MIDAS programme to store, analyse and manage inventory data;
- acquisition of portable digital recorder.

Once the milestones mentioned above are achieved, the first cycle of NFI for Jamaica can commence.

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Chapter 19

MEXICO

NATIONAL FOREST AND SOIL INVENTORY OF MEXICO

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19.1 HISTORICAL OVERVIEW OF NATIONAL FOREST INVENTORIES IN MEXICO

The experience in forest inventories in Mexico began with the First National Forest Inventory developed between 1961 and 1985, with the support of the Food and Agriculture Organization of the United Nations (FAO), which laid the technical and administrative foundations for inventories in Mexico through the use of aerial photographs, satellite images and intensive field sampling. This project primarily aimed to assess the most commercially valuable timber forest areas. Its most important contributions were the maps at scales of 1:50 000 and 1:100 000, volume tables for the *Pinus* and *Quercus* genera, as well as various dasometric statistics and reports at national and state level (SARH, 1994; Caballero, 1999; INIF and FAO, 1965).

It was not until 1991 that the information on forest resources in the country was updated with the development of the National Forest Inventory of Grand Vision, in which indirect measurement methods were used without field data collection. Drawing on these efforts, the information gathered was integrated for the first time at national scale and vegetation maps were drawn up at a scale of 1:1 000 000, depicting forest and non-forest vegetation in 17 classes. This inventory served as the basis for the Periodic National Inventory a year later, as well as for detailing and updating the information through the use of high-resolution satellite images and the generation of maps at a scale of 1:250 000 for the entire national territory, in addition to zoning forest areas based on their suitability and function. A low-intensity field sampling was implemented in this inventory through sampling plots with systematic distribution and the storage of data in magnetic files that would later be used with geographic information systems (GIS) (SEMARNAT, 2002, 2005; SARH, 1994).

The fourth National Forest Inventory (2000) was carried out by the National Autonomous University of Mexico and is considered unfinished as only the first stage was completed, consisting of mapping based on the visual interpretation of satellite images; the fieldwork and dasometric evaluation phase was not carried out in this inventory (SEMARNAT, 2002).

Finally, since the enactment of the General Law of Sustainable Forest Development (LGDFS) in 2003, the National Forest and Soil Inventory (Inventario Nacional Forestal y de Suelos – INFyS, according to its acronym in Spanish) has been implemented as a national forest policy instrument (United Mexican States, 2004). The law grants the federal government, through the Ministry of the Environment and Natural Resources (Secretaría de Medio Ambiente y Recursos Naturales – SEMARNAT, according to its acronym in Spanish) and the National Forestry Commission (Comisión Nacional Forestal – CONAFOR, according to its acronym in Spanish), the authority to regulate the methodology and procedures for its implementation from 2004 onwards. This marks the start of a methodologically consistent, multipurpose project that is comparable over time

and updated every five years.

A Strategic Guidance Document was developed to guide the implementation of the INFyS, with the collaboration of the United States and Canadian Forest Services, Finland's Forest Research Institute, the National Institute for Forestry, Agriculture and Livestock Research of Mexico (Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias – INIFAP, according to its acronym in Spanish), and federal government agencies such as SEMARNAT, the National Institute of Statistics and Geography (Instituto Nacional de Estadística y Geografía – INEGI, according to its acronym in Spanish), and the National Institute of Ecology (Instituto Nacional de Ecología – INE, according to its acronym in Spanish). Pursuant to the aforementioned LGDFS, CONAFOR was designated as the agency responsible for implementing the INFyS.

In 2014, the INFyS was classified as Information of National Interest (Información de Interés Nacional in Spanish), pursuant to Article 78 of the Law of the National System of Statistical and Geographical Information (Sistema Nacional de Información Estadística y Geográfica), as it complies with the following four criteria: (i) generates data sets or indicators; (ii) contributes to the design and evaluation of national public policies; (iii) generates information on a periodic basis; and (iv) has a scientifically supported methodology.

The general objective of the INFyS is to generate maps and statistical information on the country's forest ecosystems and soils in order to support the design, implementation and evaluation of national policy aimed at promoting forest development. The inventory also seeks to obtain information on the extent and location of forest lands and lands that are predominantly forest; the quantification of forest resources, including information on environmental goods and services and environmental impacts; change dynamics in forest cover with deforestation and degradation trends; sustainability criteria and indicators, and information on emissions reduction stemming from actions to prevent deforestation and forest degradation by legal mandate; among other complementary information such as species diversity, natural regeneration, forest health, condition of soils and forest combustible materials, among others. The INFyS is one of the basic components of the National Forest Monitoring System that provides information for the development of other planning instruments such as Forest Zoning, the National Inventory of Greenhouse Gas and Compound Emissions from the forestry sector, the land use and vegetation map, and forest cover maps.

To date, there are two completed sampling cycles (2004–2009 and 2009–2014), which have enabled the comparison and analysis of trends in national forest resources. Two reports on results have been published with forest indicators for each cycle, which are available in the National Forest Information System (Sistema Nacional de Información Forestal – SNIF, according to its acronym in Spanish) (https://snif.cnf.gob.mx/).

The third measurement cycle (2015–2020) is currently in the stage of integration and analysis; the base sampling grid is composed of 26 220 clusters distributed throughout the country, with coverage in all ecosystems, which is optimal for the characterization of these plant communities (see Table 19.1 and Figure 19.1).

In addition, this information was the basis for the development of 32 State Forest and Soil Inventories (Inventarios Estatales Forestales y de Suelos in Spanish).

TABLE 19.1

Historical overview of National Forest and Soil Inventories

Inventory cycle	Implementation period	Scale	Sampling design	Number of sampling units
INFyS 1	2004–2009	National	Two-stage systematic stratified cluster sampling	26 220
INFyS 2	2009–2014	National	Two-stage systematic stratified cluster sampling	26 220
INFyS 3	2014–2019	National	Stratified cluster sampling	26 220

Source: Prepared by the authors.

FIGURE 19.1

Sampling grid of the National Forest and Soil Inventory

The boundaries shown and the names and designations used on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any countries, territories, cities, areas, authorities, or delimitation of their frontiers or boundaries. Dotted lines on maps represent approximate boundaries for which there may not yet be full agreement.

Source: **CONAFOR (National Forestry Commission).** 2020. I. Inventario Nacional Forestal y de Suelos. In: *Sistema Nacional de Información y Gestión Forestal.* Mexico City. Cited 8 November 2021.

19.2 TERMS AND DEFINITIONS RELEVANT TO THE IMPLEMENTATION OF THE MOST RECENT NATIONAL FOREST AND SOIL INVENTORY

The reference framework for the delimitation of forest lands and their vegetation in Mexico is based on the ecological, floristic and physiognomic information group of the land use and vegetation series, published by INEGI and whose classification system is based on the works of Rzedowski (1978) and Miranda and Hernández-X. (1963).

The INFyS characterizes forest resources at the national level based on the aforementioned information from INEGI and, according to the definition of forest vegetation set forth in the LGDFS, these resources include vegetation that develops naturally in forests, jungles, arid and semi-arid zones and other natural ecosystems, as well as the soils of forest lands and lands that are predominantly forest.

According to national regulation, forests are defined as:

> *... forest vegetation mainly in temperate climate zones, dominated by perennial woody species that develop spontaneously, with a canopy greater than ten percent of the land area it occupies, provided that they form masses larger than 1 500 square metres (article 2 (United Mexican States, 2014), section V, LGDFS Regulation).*

The variables and thresholds for forest are shown in Table 19.2 and are considered a subset of the forest resources in which tropical climate vegetation or forests are typically included for reporting purposes, as well as all types of woody vegetation found in the country.

The dasometric information to characterize forest ecosystems is collected in the field in the tree stratum, following the INFyS methodology. At individual level, variables such as normal diameter and total height are recorded to estimate timber

volume and above-ground biomass, among other indicators, using allometric equations generated specifically for the country or particular region. Table 19.2 provides the main definitions used to implement the INFyS.

It is worth mentioning that, according to the national classification system, a total of 60 plant communities or vegetation types have been defined in Mexico with their respective development (primary and secondary) and vegetation phases (secondary tree, shrub and herbaceous). In the INFyS, these are grouped by biological affinity into 11 forest formations for the purposes of national reports (Figure 19.2) and are generalised into forests and other wooded land for international reports, such as the Global Forest Resources Assessment (FRA). In addition, the land use and vegetation series include information on agricultural and livestock land, which is categorised as non-forest land or other land, as shown in the table of national definitions and correspondence (Table 19.3).

TABLE 19.2

Summary of definitions used in the implementation of the National Forest and Soil Inventory

Term	Definition	Variables and thresholds
Forest	Forest vegetation mainly in temperate and tropical climate zones (forests and rainforests), dominated by perennial woody species that grow spontaneously, with a canopy greater than ten percent of the land area it occupies, provided they form masses larger than 1 500 square metres (LGDFS Regulation, Article 2, Section V).	Minimum area: > 0.5 ha Canopy cover: > 10% Tree height: 5 m Exclusions: land predominantly under agricultural or urban use
Other wooded land	Forest vegetation mainly in semi-arid and arid zones, dominated by spontaneously growing shrubs species, with a canopy greater than ten percent of the area it occupies, provided that they form masses greater than 1 500 square metres (definition of forest vegetation in arid zones [LGDFS Regulation], corresponding to the definition of other wooded land [FAO, 2018]).	Minimum area: > 5 ha Tree height: > 5 m Canopy cover: 5% to 10% (trees capable of reaching these minimum thresholds *in situ*) Mixed cover of shrubs, brushwood or trees: > 10% Exclusions: land predominantly under agricultural use
Other land	Area not classified as forest or other wooded land	
Volume	Total tree volume (TTR): Volume of stem and bark in cubic metres, without branches (NOM-152-SEMARNAT-2006, 2006), estimated from allometric models that include normal diameter and total height as dependent variables.	Standing living and dead trees from 7.5 cm normal diameter (measured at 1.3 m)
Biomass	Above-ground living biomass, which includes the whole tree consisting of the stem, stump, branches, bark and leaves, estimated from allometric models.	Living trees from 7.5 cm normal diameter (measured at 1.3m)

Source: **FAO.** 2018. *Global Forest Resources Assessment: Terms and definitions FRA 2020.* Forest Resources Assessment Working Paper 188. Rome, FAO.; **INEGI.** 2016. Conjunto de Datos Vectoriales de Uso de Suelo y Vegetación. Escala 1:250 000. Serie VI (Capa Union). edición: 1. Instituto Nacional de Estadística y Geografía. Aguascalientes, México.; **Mexican Official Standard NOM-152-SEMARNAT-2006.** Secretariat of Environment and Natural Resources, Mexico City, Mexico, 6 August 2008.; **The United Mexican States. *LGDFS (Regulations of the General Law for Sustainable Forest Development).*** President of the Republic, Mexico City, Mexico. Latest reform published on 31 October 2014.

TABLE 19.3

National definitions for forest formations and correspondence per vegetation type

	Definition	Type of vegetation	Correspondence FRA 2020
Coniferous	Arboreal, semi-arboreal or occasionally shrub communities, mainly of temperate and semi-cold zones; with minimal variation of coniferous species. They are found from sea level to the upper limit of arboreal vegetation, which in Mexico is around 4 000 metres above sea level (masl) (Rzedowski, 2006; INEGI, 2015).	Fir forest	Forest
		Pine tree	Forest
		Cedar forest	Forest
		Sacred fir forest	Forest
		Tascate forest	Forest
		Coniferous brushland	Other wooded land

TABLE 19.3 (CONTINUED)

	Definition	Type of vegetation	Correspondence FRA 2020
Coniferous and broadleaved	Includes mixed pine-holm oak or holm oak-pine forests depending on the dominant species; they are considered as transitional phases in the development of pure forests, although in Mexico they can be considered climax vegetation due to their vast distribution (Rzedowski, 2006). They are widely distributed in the highlands of the country's mountain ranges.	Holm oak-pine forest	Forest
		Pine-holm oak forest	Forest
Broadleaved	Includes plant communities with a dominance of the *Quercus* genus, characteristic of mountainous areas that make up most of the vegetation cover in temperate and semi-humid climates in Mexico, together with pine forests, also found in regions with a warm climate, areas that are quite humid, and even in semi-arid zones (Rzedowski, 2006). It also includes gallery forests, tree communities that form narrow strips of vegetation along the riverbanks or streams under conditions of favourable edaphic humidity, in places with temperate to dry climates.	Holm oak forest	Forest
		Gallery forest	Forest
Mesophilous forest	Characterized by the presence of dense to very dense arboreal vegetation, with epiphytes and ferns, located mainly in mountains, ravines and sites with favourable conditions of humidity and frequent fog. In Mexico it is located between 600 masl and 2 800 masl (INEGI, 2015; Rzedowski, 2006).	Mountain mesophilous forest	Bosque
High and medium rainforests	Ecosystems found in warm and humid climate zones (mean annual rainfall ranging from 1 100 mm to 4 000 mm and from 1 000 mm to 1 600 mm, respectively). They are distributed on sites ranging in altitude from sea level to 1 500 m and up to 2 500 m. The high rainforests are the lushest and most developed rainforests in the country, characterized by trees whose height exceeds 30 m. The trees have straight stems and tabular roots, also called buttresses, and have more or less spherical crowns. Medium rainforests share the same characteristics, but trees are smaller (from 15 m to 25 m tall), although they can be equal to those of the high evergreen forest; there is more light inside this community than in the high rainforest, which favours the development of understorey plants (semi-woody or non-woody plants, no taller than 1.5 m) (INEGI, 2015; Pennington and Sarukhán, 2005).	High evergreen rainforest	Forest
		High semi-evergreen rainforest	Forest
		Medium deciduous rainforest	Forest
		Medium evergreen rainforest	Forest
		Medium semi-deciduous rainforest	Forest
		Medium semi-evergreen rainforest	Forest
Low rainforests	Defined by low tree species ranging from 4 m to 10 m in height and eventually reaching 15 m, it groups together communities of warm humid and subhumid climates distinguished by tree species that lose their leaves during the dry season and communities of different varieties of thorny rainforest in drier conditions; at the same time, these plant communities are more humid than those of the brushlands and occupy deeper soils (Rzedowski, 2006).	Low deciduous rainforest	Forest
		Low thorny deciduous rainforest	Forest
		Low thorny semi-evergreen rainforest	Forest
		Low evergreen rainforest	Forest
		Low semi-deciduous rainforest	Forest
		Low semi-evergreen rainforest	Forest
Mangrove	Dense community, dominated mainly by evergreen trees or shrubs with reproductive adaptations such as viviparity and that are specially adapted to flooded areas and tidal waters; their root systems have become pneumatophores and buttress roots, which have the respective functions of oxygen uptake from the air and oxygen fixation in the muddy ground, with heights that can vary from 1 m to 30 m. It grows on the margins of coastal lagoons and estuaries and at the mouths of rivers and streams, but also in the shallow, muddy areas of the coasts; always in deep soils, in flooded sites without strong waves or with stagnant water (INEGI, 2015; Pennington and Sarukhán, 2005).	Mangrove	Forest
Other plant associations	Includes several types of forest vegetation with tree stratum species, with a very diverse physiognomy and floristic composition, and which, due to their peculiar characteristics, cannot be included in other forest formations.	Cultivated forest	Forest
		Induced forest	Forest
		Natural palm grove	Forest
		Gallery rainforest	Forest
		Petén vegetation	Forest
		Induced palm grove	Other land
		Savannah	Other land
		Savannoid	Other land

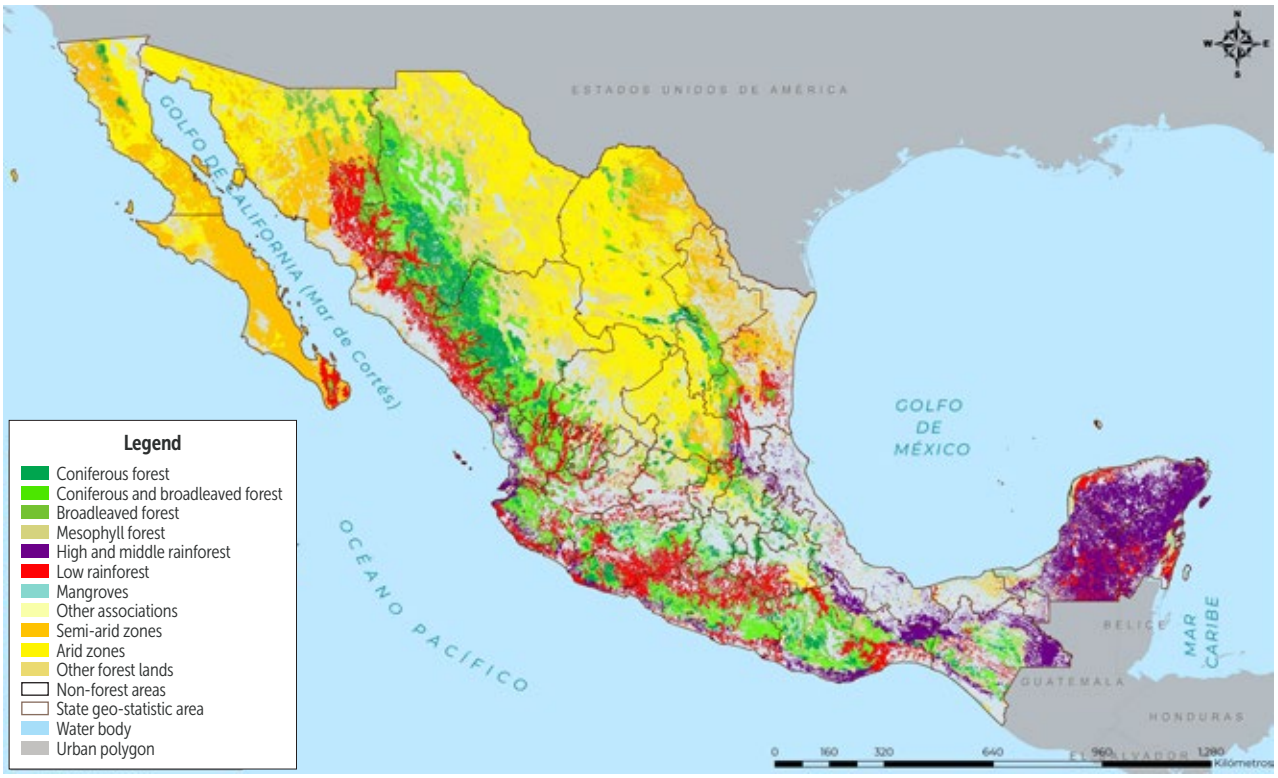
TABLE 19.3 (CONTINUED)

	Definition	Type of vegetation	Correspondence FRA 2020
Semi-arid zones	Plant communities that develop in areas with severe moisture deficiency during most of the year, but with a distinct wet season. The average annual rainfall in the northern regions ranges from 200 mm to 350 mm, and in the southern and central regions of the country from 400 mm to 800 mm (CONAZA and UACH, 2004). These areas are home to a large number of plant species, which have evolved with specific morphological characteristics to adapt to the restrictive environmental conditions in which they develop, which is why a high proportion of them are endemic species (INEGI, 2015).	Mesquite forest	Forest
		Tropical mesquite forest	Forest
		Chaparral	Other wooded land
		Tamaulipas thorny brushland	Other wooded land
		Sarcocaulon brushland	Other wooded land
		Sarcocaulon brushland	Other wooded land
		Foggy sarco-crassicaule brushland	Other wooded land
		Submontane brushland	Other wooded land
		Subtropical brushland	Other wooded land
		Xerophilous (dry) mezquite forest	Other wooded land
		Gallery vegetation	Other land
Arid zones	Plant communities distributed mainly in the arid zones of the country, characterized by a very short rainy season (less than three months) and low rainfall; the average annual rainfall generally does not exceed 250 mm, with mean annual temperatures ranging from 18 °C to 29 °C. Areas very diverse in life forms and species, with a predominance of succulent and semi-succulent plants (INEGI, 2015).	Crasicaulon brushland	Other land
		Microphyllous desert brushland	Other land
		Rosetophilous desert brushland	Other land
		Coastal rosetophilous brushland	Other land
		Sandy desert vegetation	Other land
Other forest areas	Well-defined plant communities dominated by herbaceous species, including gypsophilous vegetation, which grow on chalky and halophytic soils in the endorheic basins of arid and semi-arid zones; grassland vegetation areas dominated by grasses (natural grassland, highland grasslands and gypsophilous grasslands) and wetlands linked to the aquatic environment or to the soil more or less permanently saturated with water (popal and tular) (INEGI, 2015).	Gypsophilous grassland	Other land
		Halophytic grassland	Other land
		Natural grassland	Other land
		Popal	Other land
		Highland grassland	Other land
		Tular	Other land
		Coastal dunes vegetation	Other land
		Gypsophilous vegetation	Other land
		Xerophilous halophilic vegetation	Other land
		Halophilic hydrophilic vegetation	Other land
		Secondary herbaceous vegetation	Other land
Non-forest land	Areas that do not have forest cover, either due to land use change processes such as urban areas and agricultural land, or due to natural characteristics.	Without vegetation	Other land
		With no apparent vegetation	Other land
		Cultivated and induced grassland	Other land
		Wet, rainfed and irrigated agriculture	Other land
		Human settlements	Other land
		Urban zone	Other land
		Aquaculture	Other land

Note: FRA: Global Forest Resources Assessment.
Source: **INEGI.** 2015. *Guía para la interpretación de cartografía: uso del suelo y vegetación, escala 1:250,000, serie V.* Mexico City.; **Pennington, T.D. & Sarukhán, J.** 2005. Árboles tropicales de México: Manual para la identificación de las principales especies, 2nd Ed. Mexico City, Fondo de Cultura Económica, National Autonomous University of Mexico.; **Rzedowski, J.** 2006. *Vegetación de México*. 1st Ed. (digital). Mexico City, National Commission for the Knowledge and Use of Biodiversity.

FIGURE 19.2

Map of forest formations based on the land use and vegetation map of the National Institute of Statistics and Geography



The boundaries shown and the names and designations used on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any countries, territories, cities, areas, authorities, or delimitation of their frontiers or boundaries. Dotted lines on maps represent approximate boundaries for which there may not yet be full agreement.

Source: **CONAFOR.** 2018a. *Inventario Nacional Forestal y de Suelos. Informe 2009-2014*. Zapopan, Mexico.

The map shown in Figure 19.2 provides the frame of reference for the distribution and land area of vegetative cover, based on the vector data set of the INEGI land use and vegetation map at a scale of 1:250 000. This area considers 54 plant groups or vegetation types, represented throughout the country and included in 11 forest formations (CONAFOR, 2018a).

19.3 SAMPLING DESIGN

The INFyS has a strategic function whose semantic resolution is based on INEGI's vegetation classification system. Thus, the target population and sampling design of the INFyS are determined from the land use and vegetation map, as is the spatial resolution at a scale of 1:250 000, which is considered optimal for responding to information needs at the national level.

For field data collection, a two-stage, stratified systematic cluster sampling is used, with a five-year timeframe (SEMARNAT *et al.*, 2004).

The INFyS target population consists of all naturally growing forest resources in the country, including temperate and tropical forests or rainforests, as well as arid and semi-arid zones, palm groves, mangroves, hydrophilic communities and other forest areas.

To characterize these plant communities, large groups or strata were defined, considering common characteristics such as ecological and floristic affinity, as well as their condition, statistical variability and their relevance to forestry. The reporting needs of the country were also taken into account in order to reduce sampling error and improve the accuracy of the expected results. In this way, forests and rainforests, semi-arid communities, and arid communities can be differentiated as the three main base strata for the methodological design of the INFyS (CONAFOR, 2018a).

The cartographic basis for the stratification and planning of the field data collection for each sampling cycle is detailed below:

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- first inventory cycle (2004–2009): land use and vegetation map, series III, published in 2002;
- second inventory cycle (2009–2014): land use and vegetation map, series IV, published in 2007;
- third inventory cycle (2015–2020): land use and vegetation chart, series V, published in 2012.

In general, a stratified systematic sampling system was used , via an equidistant grid of 5 kilometres (km) by 5 km that divides the country into a uniform grid and establishes a clear and uniformly distributed sampling intensity throughout the territory and in all existing vegetation types. Primary sampling units (PSUs) or clusters are spatially distributed over this grid according to three different distances, differentiated according to the identified strata, as described in Table 19.4, with more samples taken in the more diverse ecosystems (SEMARNAT *et al.*, 2004).

This design provides the possibility of intensifying sampling in areas with more diversity and contributes to obtaining a higher statistical accuracy in subgroup estimates, for instance, the subgroups reported by INFyS in 11 forest formations, as shown in Figure 19.3. Furthermore, the network of points every 5 km and the continuous nature of this national inventory are designed such that the number of sampling units can

be increased to provide more detail, with the aim to conduct state-level and/or operational (management) inventories, or to survey areas of specific interest, such as those with greater change dynamics.

The national sample of the INFyS comprises a total of 26 220 PSUs or clusters (Table 19.5), which are mainly concentrated in forest and rainforest ecosystems, due to a higher sampling intensity in these areas given their composition; one-third of these clusters are located in more homogeneous areas, therefore, a lower sampling intensity is required.

In terms of timing, the entire sample is obtained in five-year cycles, through the systematic collection of field data in 20 percent of the total number of clusters each year. Following the layout of the sampling grid, each plot is assigned a consecutive measurement number and data are collected in about 5 200 clusters each year, depending on the availability of financial resources and the possibility to access the sites to be assessed. In this way, at the end of each five-year cycle, representative information for all vegetation types is obtained in a timely and cumulative manner for the whole country (Figure 19.4).

TABLE 19.4

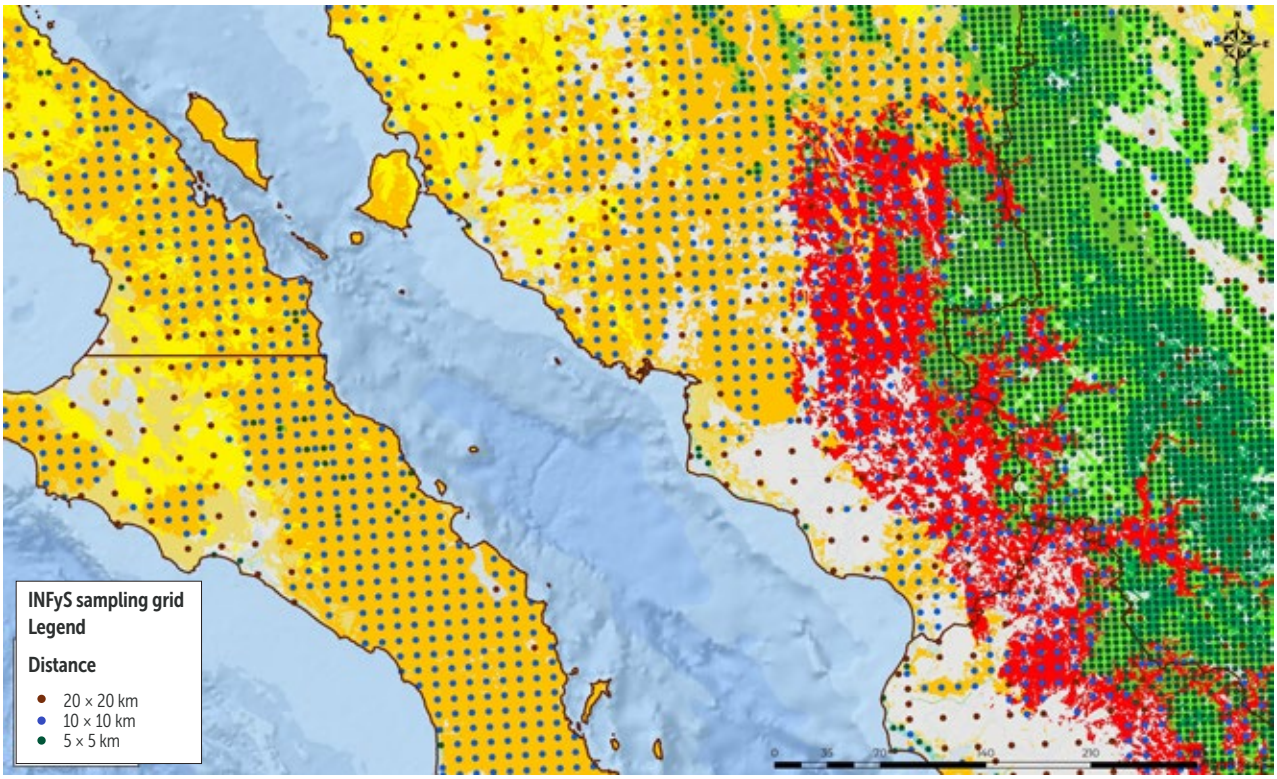
Distances per stratum of the sampling grid for the National Forest and Soil Inventory

Distance (km)	Vegetation group		Sample ratio (%)
5 x 5	Forests and rainforests	Forest, cultivated forest, gallery forest, mangrove forest, palm grove, high and medium rainforest	71
10 x 10	Semi-arid communities	Semi-arid zones, low rainforest and underwater communities	16
20 x 20	Arid communities	Arid zones and others, including non-forest areas	13

Source: **SEMARNAT (Secretariat of Environment and Natural Resources), CONAFOR, INEGI, INE & INIFAP (National Institute for Forestry, Agriculture and Livestock Research).** 2004. *Documento estratégico rector del Inventario Nacional Forestal y de Suelos.* Mexico City.

FIGURE 19.3

Distribution of clusters of the National Forest and Soil Inventory per sampling stratum



The boundaries shown and the names and designations used on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any countries, territories, cities, areas, authorities, or delimitation of their frontiers or boundaries. Dotted lines on maps represent approximate boundaries for which there may not yet be full agreement.

Source: **SEMARNAT, CONAFOR, INEGI, INE & INIFAP (.** 2004. *Documento estratégico rector del Inventario Nacional Forestal y de Suelos.* Mexico City.

TABLE 19.5

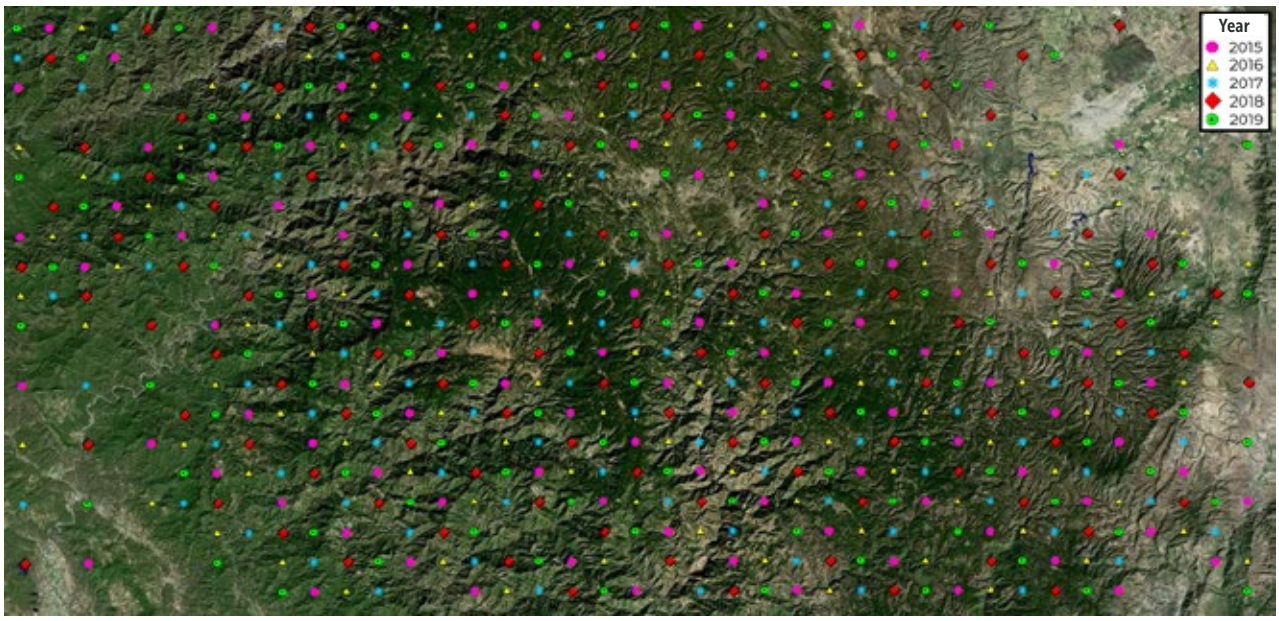
Sampling design characteristics of the National Forest and Soil Inventory

Name of the region	Total area (1 000 ha)	Number of sampling units			Total number of sampling units
		Forest	Other wooded land	Other land	
National	137 845.14	19 542	1 912	4 766	26 220

Source: Prepared by the authors.

FIGURE 19.4

Annual distribution of clusters



Source: Prepared by the authors.

The sampling design, sample size and shape of the sites, as well as the variables for INFyS implementation, are the result of previous work carried out by INIFAP for SEMARNAT, as a continuation of the National Forest Inventory of the year 2000. For the latter, a preliminary forest survey was carried out in the Lerma Chapa and Pánuco basins to determine the statistical parameters used in the implementation of the INFyS starting in 2004 (SEMARNAT *et al.*, 2004).

The detailed characteristics of the INFyS sampling design, as well as the methodologies for the collection of field variables, are described extensively in the INFyS field manuals, published by CONAFOR in digital format; these manuals contain the specifications and technical requirements of the information collected.

19.4 SAMPLING UNIT DESIGN

The INFyS methodology consists of two levels of sampling; one of these focuses on the PSU or cluster, where general information on the location and its physical and geographical characteristics is collected.

Conceptually, a cluster represents a one-hectare (ha) plot established for the selection of the sample to be studied, which is composed of four secondary sampling units (SSUs), sites or subplots, geometrically arranged in an "inverted Y" shape from the north. For the years 2004 to 2012, the shape of the SSUs varied from rectangular, in the case of rainforests, to a circular shape for other types of vegetation. However, starting in 2012, the shape of the sites has been circular for all types of vegetation.

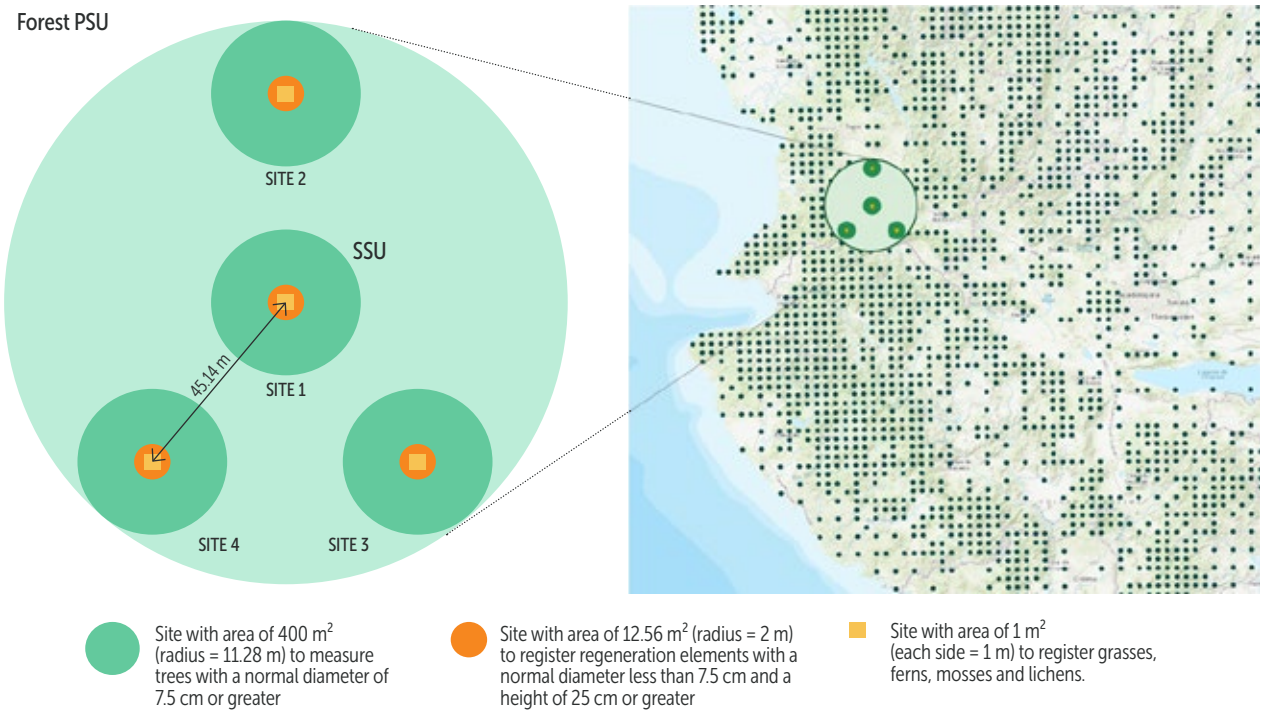
In each of the four SSUs or subplots, most of the dasometric and quantitative information is collected at the individual level for the characterization of the three plant strata (tree, shrub and herbaceous); this serves as base information for estimating statistical parameters and indicators for forest assessment and monitoring, as well as population inferences.

The special features of the plot design, the protocol for measuring variables, and the field formats are documented annually in the Field Sampling Procedures Manual, available in the SNIF.

Figure 19.5 shows the complete configuration of a cluster, where site or subplot 1 corresponds to the centre and georeferencing point of the cluster. Sites or subplots 2, 3 and 4 are peripheral and are arranged at 0°, 120° and 240°, respectively, with a separation of 45.14 metres (m) from the centre of site 1; these are known as 400 m² sites due to the land area they occupy. In turn, the 12.56 m² sampling sites are established concentrically within the SSUs, as well as the square sites of 1 m². Finally, the forest combustible materials sampling transects, which are located at site 3, are plotted.

FIGURE 19.5

Primary sampling unit or cluster design of the National Forest and Soil Inventory



Note: PSU: primary sampling unit; SSU: secondary sampling unit.
Source: **CONAFOR.** 2018a. *Inventario Nacional Forestal y de Suelos. Informe 2009-2014.* Zapopan, Mexico.

As described in the INFyS results report 2009–2014 (CONAFOR, 2018a), the following information is collected at each site or subplot:

- Subplot of 400 m²: trees with a normal diameter (ND) of 7.5 centimetres (cm) or more are measured and recorded. Biological forms such as columnar cacti, palmillas or yuccas are sampled, as for the INFyS they are classified as major vegetation; there are some differences in the field survey with respect to trees in those variables that do not qualify for measurement because they have different growth forms.
- Subplot of 12.56 m²: the natural regeneration is measured and recorded by genus, frequency and qualitative variables. Sampling focuses on plants or small trees that are at least 25 cm high, provided that their ND is less than 7.5 cm. Likewise, in the case of arid and semi-arid communities, representative shrubs are recorded, including invasive species and native or induced grasses (regeneration and minor vegetation sections).
- Subplot of 1 m²: herbaceous plants, ferns, mosses and lichens in the herbaceous layer are measured and recorded, as well as other soil characteristics (minor vegetation and land cover section).
- Sampling transects: information on forest combustible materials and soils is recorded in four linear transects measuring 15 m in length, generally located at site 3.

19.5 LAND AREA, VOLUME AND BIOMASS CALCULATION

The reference framework for understanding the distribution and extent of forest vegetation is the aforementioned land use and vegetation map published by INEGI; various series of maps were developed using the same methodology and classification system from 1993 onwards, which makes them compatible with each other. The maps are generated based on qualitative fieldwork and photointerpretation techniques of Landsat and SPOT satellite images, depending on the series. The working scale is 1:250 000, establishing a minimum mapping unit of 50 ha for ecological, floristic and physiognomic information (plant communities), while for agricultural, livestock and forestry information (induced and cultivated forest) and complementary information (land use), the minimum mapping unit is 1 ha (INEGI, 2015).

The cartographic base used for reporting the forest land area and estimating statistical parameters for each sampling cycle is as follows:

- first inventory cycle (2004–2009): land use and vegetation map, series IV, published in 2007;
- second inventory cycle (2009-–2014): land use and vegetation map, series VI, published in 2014;
- third inventory cycle (2015–2020): in the reporting process.

The estimated dasometric parameters with the data collected through the INFyS – such as tree density, basal area, crown, timber stocks, biomass, stored carbon, average annual increment and percentage of damaged trees – are obtained from the calculation of the parameter at the individual tree level and its estimation at the substratum, stratum and ecosystem level (CONAFOR, 2018a).

As regards volume and biomass, the estimate is based on a selection of trees sampled according to their taxonomic identity. Given that various living species such as palms, arborescent ferns, bamboos and others are registered, only "trees" or "indeterminate" woody plants are considered; the latter applies to cases where the dimensions, families or genera suggest a high probability of being classified as trees. In addition, selection is made according to the condition of living or standing dead trees, in alignment with the definitions of these terms. Table 19.6 shows the number of allometric equations and references used for the calculation of volume and individual biomass, developed for the country or even for a specific region (CONAFOR, 2018a).

Given the high number of species and records that are identified (around 1.3 million records per sampling cycle), defining the most appropriate allometric equation to estimate volume and/or biomass is a process in which direct and indirect assignments are identified using a decision tree to select the most appropriate equation; this process is carried out in three phases: i) equation assignment per criterion; ii) association of the equation to records or trees in the sample; and iii) calculation of the parameter.

The assignment of equations follows hierarchical criteria that help to assign an existing equation (direct

assignment) or by affinity (indirect assignment). It is performed at several levels, depending on the applicability of the equation, according to the following priorities: (i) taxonomic identity (species, genus, family, affinity by genus, general equation); (ii) source (by reference or most recent source); (iii) area of influence (distribution based on the geospatial relationship by joining layers such as ecoregions, Forest Management Units [Unidades de Manejo Forestal – UMAFOR, according to its acronym in Spanish] and entities); and (iv) statistical parameter (R-squared [R^2] and sample size), which was implemented for the completion of the 2009–2014 INFyS results report (CONAFOR, 2018a).

It is worth mentioning that, according to article 7, section LXXVII of the LGDFS, a UMAFOR is a "territory with physical, environmental, social and economic similarities, delimited by the Commission, in coordination with the Federal Entities and with the opinion of the State Forest Councils," whose purpose is to achieve sustainable forest management, orderly planning of forest activities and efficient management of forest resources.

Once the volume or biomass has been calculated for each individual, the estimate is made at the PSU or cluster, substratum and stratum level (with the corresponding land area taken from the land use and vegetation map).

The sampling area is decisive in gaining a more accurate average per hectare, for which specific ratio estimators are used for the INFyS, as proposed by Velasco *et al.* (2005). These are developed to compensate for the bias of the sample mean, which is the result of the differences in the land areas sampled in each cluster; the source of variation is identified in the number of sites or SSUs surveyed in the field and which directly affect the land area. Theoretically, there are four SSUs per cluster; however, the conditions for accessing the site and collecting data in the field are not always met, so it is important to identify and differentiate each sampled land area.

For their systematisation, both the dasometric estimates and the decision tree for the assignment of equations were developed with the support of the statistical program R.

TABLE 19.6

Equations used for volume and biomass calculations

Variables	Equation	Reference
Total volume (m^3)	A total of 1 105 equations designed for the calculation of stem volume with bark (total tree volume), with direct and indirect applicability at the following levels: – 967 at species level – 145 at genus level – 18 at species group level – 24 at specific region level	Models of the First National Forest Inventory (NFI) 1961–1985 (CONAFOR, 2018b) Biometric models of the project "Biometric system for forest management planning in ecosystems with productive potential in Mexico," financed with resources from the Sectoral Fund (CONACYT-CONAFOR, 2016; CONAFOR, 2018b)
Biomass and carbon stocks (t)	A total of 347 allometric models designed for the calculation of biomass and carbon, with direct and indirect applicability to the following: **biomass** – 273 at species and infraspecies level (covering 147 species and 90 genera) – 42 at genus level (covering 13 genera) – 14 at general level (by vegetation type, ecoregion) **carbon** – 18 at species and infraspecies level (covering 15 species and infraspecies, and 9 genera)	Database: Biomass and Carbon Allometric Models of the Biomass and Carbon Estimate System (SEByC) (CONAFOR, 2019)

Notes: CONACYT: National Council of Science and Technology; CONAFOR: National Forestry Commission.

Source: **CONAFOR & CONACYT.** 2016. Modelos biométricos. In: *SiBiFor: Biblioteca digital del sistema biométrico para la planeación del manejo forestal en ecosistemas con potencial productivo en México*. El Salto, Mexico. Cited 8 November 2021.; **CONAFOR.** 2018b. Información adicional: Ecuaciones de volumen VRTACC. Informe de Resultados 2009-2014. In: *Sistema Nacional de Información y Gestión Forestal*. Mexico City.; **CONAFOR.** 2019. *Modelos alométricos de biomasa y carbono del Sistema de Estimación de Biomasa y Carbono (SEByC).* Zapopan, Mexico, Gerencia del Sistema Nacional de Monitoreo. (unpublished).

19.6 RESULTS OF THE MOST RECENT NATIONAL FOREST AND SOIL INVENTORY

The data from the most recent sampling period and cartographic information from 2014 were used to prepare the 2009–2014 INFyS results report, which includes adjustments and improvements of field variables surveyed over time, using a data standardization process prior to statistical analysis in order to provide accurate and relevant information.

According to the INFyS methodology, this results report includes topics such as sample size, variables recorded in the field and, most importantly, the main forest indicators that characterize and quantify natural resources at the forest formation level.

Likewise, since two sampling cycles have been completed, a comparison and analysis of trends and changes that have been recorded in forest areas is included, thus allowing the generation of new indicators; such as rates of change in forest cover and causes of deforestation, changes in the forest structure reflected in variations in averages per hectare and in total stock (CONAFOR, 2018a).

According to the results, the land area of forest resources is estimated at around 137.8 million hectares, which represents 70.5 percent of the 195.6 million hectares of the national territory. Overall, wooded areas occupy 47.7 percent of the forest land area, equivalent to 65.7 million hectares; xerophilous brushlands, an important ecosystem representing

TABLE 19.7

Results of the 2009–2014 National Forest and Soils Inventory

Variable	Result	Description
Land area (thousands of hectares)	**Total forests: 137 845** **Temperate forests** – Coniferous: 8 103 – Coniferous and broadleaved: 12 950 – Broadleaved: 11 360 – Mesophilous forest: 1 787 **Tropical forests** – High and medium rainforests: 13 562 – Low rainforests: 16 464 – Mangroves: 940 – Other tree associations: 540 **Xerophilous shrublands** – Semi-arid zones: 20 330 – Arid zones: 35 975	Forest land area with reference to the year 2014, based on the land use and vegetation map, series VI, of the National Institute of Statistics and Geography and as reported in the results report of the 2009–2014 National Forest and Soil Inventory (INFyS) (CONAFOR, 2018a)
Total roundwood volume (million cubic metres)	**Total tree: 3 731 (190.1)** **Temperate forests** – Coniferous: 693 (36) – Coniferous and broadleaved: 800 (35) – Broadleaved: 356 (19) – Mesophilous forest: 183 (21) **Tropical forests** – High and medium rainforests: 1 136 (36) – Low rainforests: 534 (37) – Mangroves: 29 (6)	Total volumetric stock, based on the land area reported in the land use and vegetation map, series VI (base year 2014) (INEGI, 2016) and average volume (cubic metres per hectare) based on data from the 2009–2014 INFyS; confidence limits
Biomass (million tonnes)	**Total tree: 2 956 (142.2)** **Temperate forests** – Coniferous: 507 (22) – Coniferous and broadleaved: 694 (25) – Broadleaved: 389 (18) – Mesophilous forest: 139 (16) **Tropical forests** – High and medium rainforests: 784 (27) – Low rainforests: 411 (27) – Mangroves: 31 (6)	Total above-ground biomass stock, based on the area reported in the land use and vegetation map, series VI (base year 2014) (INEGI, 2016) and the average above-ground biomass (tonnes per hectare) from INFyS data 2009–2014; confidence limits

Source: **CONAFOR.** 2018a. *Inventario Nacional Forestal y de Suelos. Informe 2009-2014.* Zapopan, Mexico.; **INEGI**. 2016.

40.8 percent of the forest land area, equivalent to about 56.3 million hectares, is comparable to wooded areas in size and in the number of endemic species present, consisting primarily of shrubs and succulent plants (CONAFOR, 2018a). Table 19.7 provides a breakdown of the land area occupied by each forest formation.

For Mexico, the total actual growing stock volume or biomass in ecosystems – understood as the amount of established vegetation that exists in an area, country or region – is estimated by distinguishing between primary and secondary vegetation, since they often have significant differences; thus, the country's total growing stock is equivalent to the sum of the growing stock of these two types of vegetation. In this context, 97.4 percent of the country's timber stock is located in forests, representing about 3 731 million cubic metres (m^3) of standing roundwood; as for biomass, this is estimated at 2 956 million tonnes in wooded areas (Table 19.7).

It is worth mentioning that spatially explicit models (national continuous models) were developed in collaboration with researchers from the University of Delaware; these were based on the main dasometric indicators that were generated with data from the second INFyS cycle (2009–2014), with the purpose of using better tools and providing sources of updated information. The results of these models can be seen in Figure 19.6 for above-ground biomass and Figure 19.7 for average volume (CONAFOR, 2018a).

FIGURE 19.6

Distribution of the average above-ground forest biomass per hectare

The boundaries shown and the names and designations used on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any countries, territories, cities, areas, authorities, or delimitation of their frontiers or boundaries. Dotted lines on maps represent approximate boundaries for which there may not yet be full agreement.

Source: **CONAFOR.** 2018a. *Inventario Nacional Forestal y de Suelos. Informe 2009-2014.* Zapopan, Mexico.

19.7 IMPLEMENTATION AND QUALITY CONTROL

Data collection for the INFyS is conducted by companies that are responsible for both collecting data in the field and entering data into the database. Likewise, companies are hired to carry out the external supervision of the field crews. In both cases, the companies are hired through national and international public tenders, depending on the amount of funding involved. The tender documents specify the various requirements that suppliers should meet in terms of quality control; these consist of a set of planned and systematic actions implemented within a company's Quality System, based on the Quality Assurance and Quality Control System (Sistema de Aseguramiento y Control de Calidad – SACC, according to its acronym in Spanish) designed by CONAFOR.

These actions are aimed at guaranteeing the quality of field sampling and the proper recording of qualitative and quantitative information as per INFyS manuals and instructions; they should be verifiable in order for both the company and CONAFOR to be confident that SACC requirements are being properly implemented.

To support the inventory's quality and ensure its reliability, the monitoring checks and activities conducted include the following three main components:

- Internal supervision: in addition to conducting the field survey, the companies should have a permanent internal supervision crew to verify the field data collection, including the physical evidence of the work carried out during the sampling.

FIGURE 19.7

Distribution of average timber volume per hectare

The boundaries shown and the names and designations used on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any countries, territories, cities, areas, authorities, or delimitation of their frontiers or boundaries. Dotted lines on maps represent approximate boundaries for which there may not yet be full agreement.

Source: **CONAFOR.** 2018a. *Inventario Nacional Forestal y de Suelos. Informe 2009-2014*. Zapopan, Mexico.

- External supervision: if budgetary conditions permit, CONAFOR may conduct field supervision on 10 percent or more of the total number of clusters surveyed by the companies that are responsible for the sampling.
- Implementation of the SACC: the key concept underpinning the INFyS SACC is that of "quality testing," to verify that the INFyS data and outputs comply with the requirements established in the Field Procedures Manual and in the calls for tender and their appendices, in order to corroborate that the information is truthful, reliable and accurate.

The quality control process ends with the continuous revision, filtering and technical validation of the recorded variables to ensure the consistency of data, as a mandatory step for using the variables in the estimates to be made. This process includes the standardization of changes in the variables collected in the field throughout the current sampling cycle, and even during previous cycles when comparing them to determine changes over time.

Among the main aspects considered in this process are the standardization of terms for qualitative variables; the treatment of atypical data in quantitative variables; the consistency between dependent variables, both in terms of concepts and measurement; and the revision and linkage of accepted scientific names with synonymy under two classification systems. These include the system used by the National Commission for the Knowledge and Use of Biodiversity (Comisión Nacional para el Conocimiento y Uso de la Biodiversidad – CONABIO, according to its acronym in Spanish), referred to mainly for ferns and related species (Mickel and Beitel, 1988; Mickel, 1992), gymnosperms (McVaugh, 1992), monocotyledons (Dahlgren *et al.*, 1985) and dicotyledons (Cronquist, 1981), as well as the Angiosperm Phylogeny Group system; the latter classification is used for INFyS reporting purposes, as well as for the documentation of quality control.

19.8 OTHER RELEVANT VARIABLES COLLECTED

The INFyS comprises the measurement of about 175 vegetation and soil variables collected at the sampling sites, following the forest areas monitoring approach.

One group of variables that are considered basic or dasometric stands out, as they describe the characteristics of the forest crop. These variables are primarily related to forest productivity; within this group there are also variables that help to assess the state of the ecosystems in terms of species composition, natural regeneration, presence of pests and forest fires, environmental impacts, variables on the state of the soil, among others. Thus, from its conception, the INFyS follows a multipurpose approach for forest resource monitoring.

In view of the growing demand for information, variables of specific interest have been incorporated. These include technologies that can be encompassed within concepts such as biodiversity, carbon, fires (lying woody materials, live combustible materials and others), forest health (crown transparency and others), mangroves and aquatic communities (measurement of physico-chemical parameters and others), arid zones (characterization of their composition), hemispheric photographs and soils. Some of these variables are measured and collected at specific times and according to budget resources.

In addition to the collection of field data, specific projects have emerged as opportunities to obtain information in collaboration with other institutions, the most relevant of which are mentioned below:

- Botanical collections to correctly identify the tree species in the sampling sites (traditional and molecular analysis), in collaboration with the Institute of Biology of the National Autonomous University of Mexico.
- Adjustment and inclusion of soil variables from sampling and laboratory analysis, in collaboration with the National Network of Laboratories for Soil Use, Conservation and Management, in order to help reduce the uncertainty associated with the determination of carbon content in soil and leaf litter, as well as other physico-chemical variables of soils.

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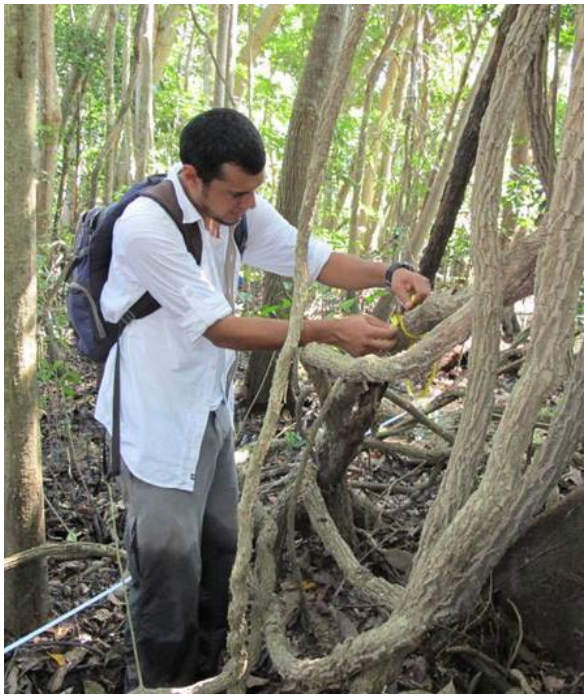
- Data on biodiversity, including variables on fauna through camera traps, as well as recorders with microphones to capture a wide range of sounds, and the collection of animal traces, such as footprints and faeces. This project, named Wide Coverage System for Monitoring Diversity (Sistema de Amplia Cobertura para el Monitoreo de Diversidad), was implemented in coordination with CONABIO, the National Commission of Natural Protected Areas, as well as the Mexican Fund for the Conservation of Nature.
- Recent deforestation estimate using the sampling or reference grid approach, which is performed through the multitemporal analysis of various satellite images from the period 2000 to 2018 over the coordinates of the INFyS sampling grid, with a total sample coverage of 26 220 clusters. This analysis was carried out with the support of interpretation tools such as Collect Earth developed by FAO, which was used to determine the activities to update the reference level of forest emissions for Mexico in the context of the Reducing Emissions from Deforestation and Forest Degradation (REDD+) mechanism (https://redd.unfccc.int/submissions.html?country=mex).



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19.9 FUTURE PROSPECTS

The main commitment of the INFyS is to fully comply with its mandates, pursuant to the LGDFS, including being one of the main information sources and component of the National Forest Monitoring System (Article 34, Sections II and VII, LGDFS), together with the Forest Monitoring Satellite System and the National Monitoring, Reporting and Verification System, as well as promoting a wide use and dissemination of the data produced to meet the demand for information to support decision-making and the assessment of public policies and programmes in the forestry sector.

To this end, future reorientation and strengthening of the INFyS is being considered based on a diagnosis of the various planning, operational design and field data collection processes, with a view to streamline data collection, optimize resources, and generate relevant and timely information by means of new and more accessible technologies for users.

The main future prospects identified are as follows:

- Strengthening methodological frameworks: review of the sampling design to streamline field data collection and quality control; implement gap analysis mechanisms; improve methods to estimate basic forest attributes and integrate sustainability indicators, environmental goods and services valuation, as well as deforestation and degradation rates; implement mapping and geospatial modelling protocols; develop conceptual and manual documents; explore new methodological approaches and technological innovations.

- Information analysis and dissemination: development of efficient data storage, management and consultation tools such as “reporters” and geoportals that promote the use of internal and external information; capacity strengthening for information analysis and timely reporting with national and international technical assistance; prospective analysis of scenarios; regular reporting with national and regional information.

- Institutionalization: review and strengthen institutional arrangements with government agencies, academia and non-governmental organizations (NGOs); identify and integrate relevant statistical and cartographic information generated by other institutions; organize meetings of INFyS information users to promote innovation and report results of studies and/or research; promote the use of INFyS information for strategic decision-making at different levels.

- New technologies: consolidate the field sampling technology for higher accuracy in establishing permanent plots, such as radio frequency identification and measuring equipment; introduce new technologies to optimize field data capture and further integration of geospatial tools and technologies for mass data management.

It is important to mention that a new national forest map is currently being developed with remote sensing information as part of the National Forest Monitoring System. This new map draws on field information collected by INFyS for its validation, with the aim of having more detailed cartographic inputs that will serve to report on the extent of forest ecosystems, increase the accuracy of estimates, and conduct more detailed and timely studies.

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Chapter 20

NICARAGUA

NATIONAL FOREST INVENTORY OF **NICARAGUA**

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20.1 HISTORICAL OVERVIEW OF NATIONAL FOREST INVENTORIES OF NICARAGUA

In 2007, the first National Forest Inventory (NFI) of Nicaragua was developed by the Government of Reconciliation and National Unity (Gobierno de Reconciliación y Unidad Nacional in Spanish), led by the National Forestry Institute (Instituto Nacional Forestal – INAFOR, according to its acronym in Spanish), with technical support from the Food and Agriculture Organization of the United Nations (FAO). This initial inventory aimed to establish a baseline of information and a Forest Monitoring System with permanent sampling plots throughout the country as a primary basis for consultation by different national and international institutions, thus enabling the formulation of guidelines for the National Policy for Sustainable Forest Development, the National Forest Programme, and other strategic planning instruments implemented by regional governments (INAFOR, 2009).

The NFI contains information on the status of the different forests types, as well as socioeconomic information that is relevant to the forestry sector. With the NFI, a baseline of knowledge on the state of forests in Nicaragua has been established, including socioeconomic information on the use and services of forests and scattered trees in rural communities.

Its objectives were the following:

- *Establish a consensus at national level on the approach to the National Forest Inventory for its implementation in Nicaragua;*
- *Standardize the national forest and land use classification system, which will be used to record information;*
- *Determine the current state of the forest from a biophysical point of view, as well as its economic and socio-cultural value and the main factors affecting its development;*
- *Strengthen INAFOR's capacity in the methodological development, implementation, processing and analysis of forest information;*
- *Improve knowledge about resources and benefits provided by the country's forests and trees outside the forest;*
- *Establish a system of supervision and monitoring of national forest resources (INAFOR, 2009, p. 22).*

The NFI has a systematic sampling design for mainland Nicaragua, excluding the islands in the Caribbean Sea (Figure 20.1). Data is collected in forests and in areas with other types of land use, thus providing a diagnosis of degraded forest ecosystems. The methodological basis is taken from the FAO National Forest Monitoring and Assessment Programme (INAFOR, 2009).

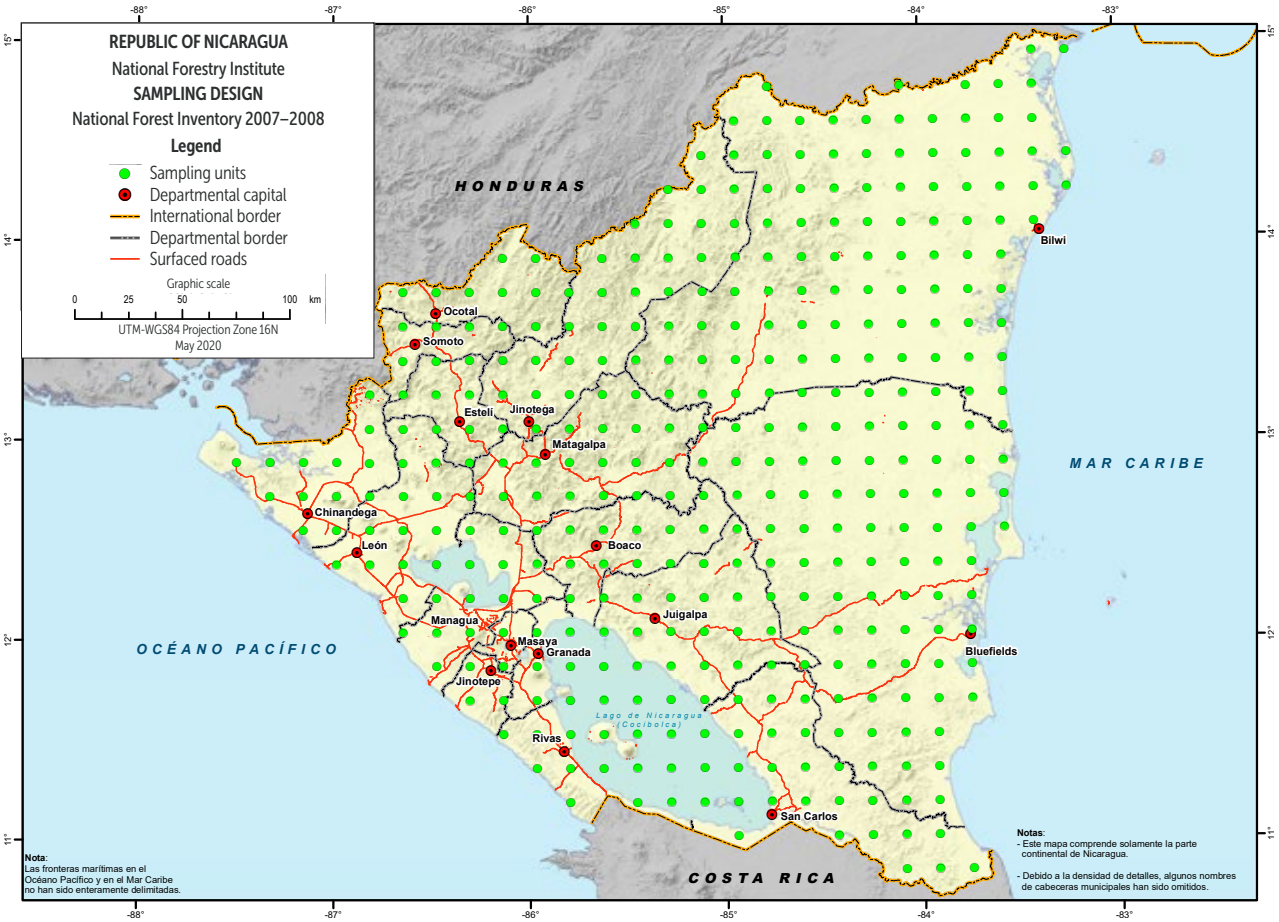
The NFI methodology was defined with the support of FAO (FAO, 2012) and adopted by INAFOR. The results obtained are reliable, transparent and robust, thanks to the NFI's design and sampling intensity, as well as the capacity and responsibility of the professionals and technicians involved. At present, INAFOR is laying the groundwork for the second NFI, remeasuring the 2007 plots and strengthening the capacities of the staff for its institutionalization.

During 2020 and 2021, the process of institutionalizing the NFI as a tool for forest monitoring has been promoted through the Forest Monitoring and Information Directorate, strengthening INAFOR's territorial capacities with the aim of improving the accuracy of the NFI in priority regions.

This approach will contribute to enhancing national technical capacities required by the Enhanced Transparency Framework under the Paris Agreement, establishing linkages with other reports, such as the following: National Greenhouse Gas Inventory (NGGI), nationally determined contributions (NDCs), baseline reporting and target setting for the land degradation neutrality mechanism of the United Nations Convention to Combat Desertification (UNCCD), the environmental and social Safeguards Information System, as well as other highly relevant systems, such as the programmes and projects registry system of the Reducing Emissions from Deforestation and Forest Degradation (REDD+) mechanism and the benefit sharing plan (BSP) that establishes the mechanisms for distributing results-based payments for REDD+.

FIGURE 20.1

Sampling design of the 2007–2008 National Forest Inventory



The boundaries shown and the names and designations used on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any countries, territories, cities, areas, authorities, or delimitation of their frontiers or boundaries. Dotted lines on maps represent approximate boundaries for which there may not yet be full agreement.

Source: **FAO.** 2008. *Manual de campo del Inventario Nacional Forestal de Nicaragua 2007-2008.* Managua, FAO.

The new NFI will respond to the following needs: establishment of quality assurance and quality control protocols applied to the collection, processing and analysis of national forest inventory data, and implementation of a second cycle of measurement, processing and analysis of data to estimate removal and sequestration factors, calculate biomass and carbon stocks, calculate changes in stocks over time, and monitor forest fires and non-anthropogenic land use changes. In addition, land cover maps will be developed in coordination with the Nicaraguan Institute of Territorial Studies, the Regional Governments of the Caribbean Coast and other users of the NFI results.

The design of the National measurement, reporting and verification System for REDD+ (2018–2040) includes periodic measurements of dasometric parameters in permanent sampling plots, distributed at the national level with a systematic grid of 371 sampling units (SU) (MARENA, 2017). The first NFI measurement cycle was conducted ten years ago and INAFOR has been conducting annual remeasurements of a percentage of all SUs since 2020, until a second measurement cycle is completed. This second NFI cycle will generate updated information on biomass stock values per forest type and the interpolation of carbon stock data to estimate emissions/removals in stable forests. Table 20.1 presents the main characteristics of the forest inventories implemented to date in Nicaragua.

20.2 TERMS AND DEFINITIONS RELEVANT TO THE 2007–2008 NATIONAL FOREST INVENTORY

The NFI classification of land use and forest types is based on FAO's accumulated experience in the definition of forests at global level (FAO, 2008). This classification consisted of five levels:

- Level 1: global land categories, according to the Global Forest Resources Assessment (FRA) programme.
- Level 2: forest classes according to their nature, either natural forest or forest plantation. For non-forest classes, natural land with trees or shrubs, other agroforestry land and other land without trees.
- Level 3: forest classes according to forest type: broadleaved, coniferous, mixed and mangrove. For areas outside forest, land use/cover types were specified.
- Level 4: forest classes are grouped according to the state of vegetation succession; for non-forest classes, the type of coffee shade, type of grassland or mining, among others, is specified.
- Level 5: this is only for forests; classes are differentiated according to canopy cover in mangrove, broadleaved and mixed forests, and according to tree density in coniferous forests.

TABLE 20.1

Historical overview of national forest inventories of Nicaragua

Inventory cycle	Implementation period	Scale	Sampling design	Number of sampling units
NFI1	2007–2008	National	Systematic (18 km × 18 km) with random start	371
NFI2	2011–2013	Departmental	Systematic (9 km × 9 km)	68
NFI3	2015–2019	Subnational	Systematic (18 km × 18 km)	50
			Systematic (9 km × 9 km)	60
NFI4	2020	Departmental	Systematic (18 km × 18 km)	14
			Systematic (9 km × 9 km)	11

Note: NFI2, NFI3 and NFI4 are second cycle campaigns.

Source: Prepared by the authors.

In order to define each class of forest, terms and definitions were drawn from the following sources: Global Forest Resources Assessment 2005 (FAO, 2006); the Regulations of Law No. 462, Law on Conservation, Promotion and Sustainable Development of the Forestry Sector (Decree No. 73-2003); and the Technical Standard for the Sustainable Management of Tropical Broadleaved and Coniferous Forests (NTON 18 001-04) (see Table 20.2).

TABLE 20.2

Summary of definitions used to implement the 2007–2008 National Forest Inventory

Term	Definition	Variables and thresholds
Forest	A plant association, either natural or planted, at any stage of the natural life cycle, with trees reaching more than 5 m in height, with a canopy cover greater than 10%, extending over 0.5 ha and with a minimum width of 20 m, which is capable of producing goods and services with or without management, and providing habitat for wildlife. The term specifically excludes trees used in agricultural production systems, e.g. fruit plantations and agroforestry systems. The term also excludes trees growing in urban parks and gardens (FAO, 2008).	Area: > 0.5 ha Canopy cover: > 10% Tree height: > 5 m
Natural broadleaved forest	Forest in which more than 70% of the basal area are broadleaved species.	70% of the basal area are broadleaved species
Natural coniferous forest	Forest in which more than 70% of the basal area are coniferous species.	More than 70% are coniferous species
Natural mixed forest	Forest composed of broadleaved and coniferous species where there is no dominance; that is, neither type exceeds 70%.	Neither type exceeds 70%
Natural mangrove forest	Forest dominated by a group of salt-tolerant tree species.	Tolerant species: *Rizophora mangle, Laguncularia racemosa, Conocarpus erectus, Avicennia nítida*
Planted forest	Forest where the species were established by direct seeding.	Direct seeding
Other land with natural trees and shrubs	Natural areas not classified as forest, greater than 0.5 ha; a combination of trees and shrubs with a canopy cover of 5% to 10%. Not agricultural or urban land.	Area: > 0.5 ha Canopy cover: 5%–10% Dominant vegetation: shrubs, natural grasslands with trees and savannahs with trees
Other land	Land not considered as forest or other land with natural trees and shrubs. It includes agricultural land, natural areas without trees, infrastructure, etc.	Tree height: not defined Canopy cover: not defined Minimum area: not defined
Volume	Total volume (cubic metres): volume of all trees greater than 10 cm diameter at breast height (DBH), from the base to the total reported height.	DBH (1.30 m): greater than 10 cm Total height: from the base to the top of the crown Commercial height: from the base to the first branch or fork Groups of species: all species identified in the field and in sample collection
Biomass	Above-ground biomass: All living above-ground biomass including stem, stump, branches, bark, seeds and leaves.	Minimum diameter: > 2 mm
	Dead wood: All dead wood biomass that is not part of the litter, whether standing, above-ground or below-ground. Dead wood includes wood lying on the surface, dead roots and stumps with a diameter equal to or greater than 10 cm or any other diameter used in the country.	Minimum diameter: 10 cm
	Litter: Carbon from all dead biomass, in various stages of decomposition above mineral or organic soil. Rootlets above mineral or organic soil are included in litter.	Diameter: greater than 2 mm and smaller than 10 cm Includes rootlets smaller than 2 mm

Source: **Nicaragua (Republic of).** *Decree No. 73-2003. Regulations of Law No. 462, Law on Conservation, Promotion and Sustainable Development of the Forestry Sector*, 2003.; **FAO.** 2006. *Global Forest Resources Assessment 2005.* FAO Forestry Paper 147. Rome, FAO.; **FAO.** 2008. *Manual de campo del Inventario Nacional Forestal de Nicaragua 2007-2008.* Managua, FAO.; **NTON 18 001-04.** 2004. *Norma Técnica para el manejo sostenible de los bosques naturales latifoliados y de coníferas*. Comité Técnico Forestal (Technical Forestry Committee), Managua, Nicaragua.

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20.3 SAMPLING DESIGN

The sampling design of the 2007–2008 NFI was systematic, covering the total area of the country, which corresponds to 129 494 square kilometres (km²). A grid was used in this design, wherein each SU was located at a distance of 10 minutes in latitude and 10 minutes in longitude (approximately every 18 km). A total of 371 SUs were selected; of these, 344 were located on land and 27 were located entirely in water (FAO, 2008). The characteristics of the design are presented in Table 20.3.

20.4 SAMPLE UNIT DESIGN

The NFI design establishes the SU as a land area of 500 m by 500 m, which contains four rectangular plots measuring 250 m by 20 m, totalling 2.0 ha as the effective measurement area.

The location and direction of the plots is as follows (Figure 20.2):

- Plot 1: located in the south-west corner of the square SU and oriented towards the north (0°–360°).
- Plot 2: located in the north-west corner and oriented towards the east (90°).
- Plot 3: located in the north-east corner and oriented towards the south (180°).
- Plot 4: located in the south-east corner and oriented towards the west (270°).

TABLE 20.3

Characteristics of the sampling design

Country	Total land area (km²)	Number of sampling units				Total number of sampling units
		Forest	Other wooded land	Other land	Inland water	
First National Forest Inventory Nicaragua	129 494	94	60	190	27	371

Source: Prepared by the authors.

TABLE 20.4

Description of the elements registered in the National Forest Inventory

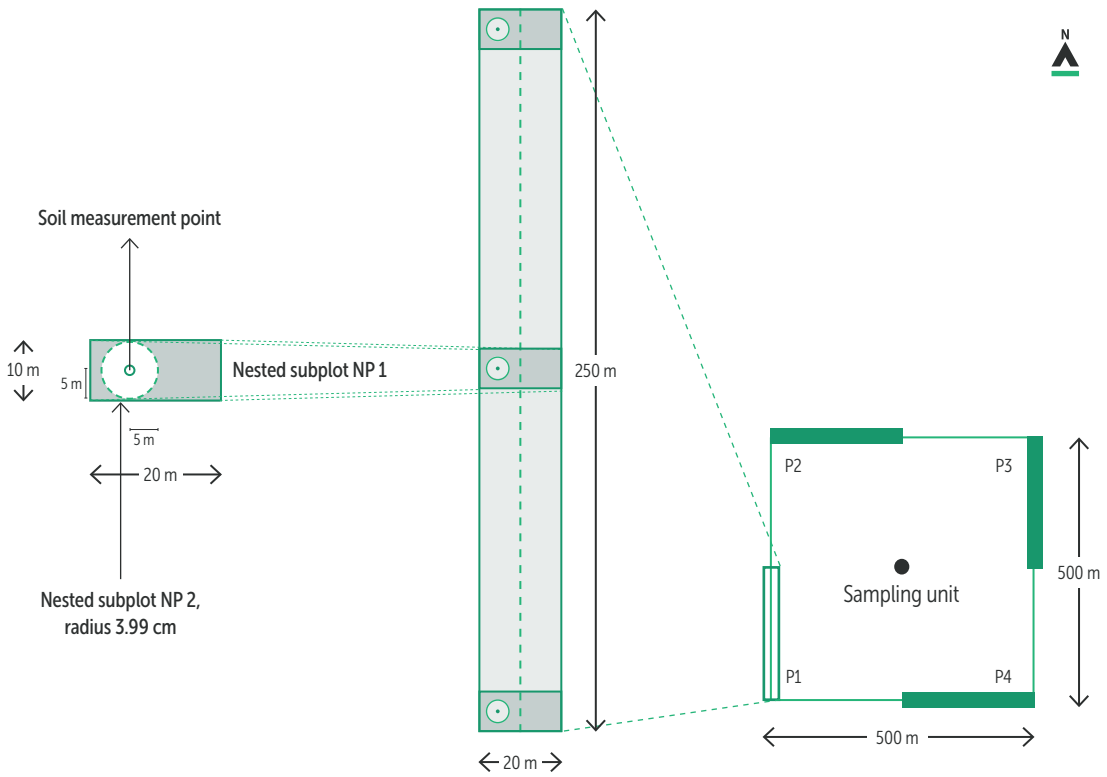
Level	Description	Elements to be recorded/measured
Sampling unit	4 plots distributed in 500 m × 500 m	Interviews with municipal offices and Indigenous and Afro-descendant territories
Plot	Rectangle: 20 m × 250 m (5 000 m^2)	Record of land use, owners/occupants, fires, barriers and live fences and geographical features Socioeconomic information on occupants Information on forest use and services Forest: trees with DBH ≥ 20 cm Outside forest: trees with DBH ≥ 10 cm
Nested subplot 1 (NP 1)	Rectangle: 20 m × 10 m (200 m^2) × 3	Forest: trees with DBH ≥ 10 cm Outside forest: not conducted
Nested subplot 2 (NP 2)	Circle: r = 3.99 m (50 m^2) × 3	Forest: trees ≥ 1.3 m high and DBH < 10 cm Outside forest: not conducted
Measurement points		Forest and outside forest: ground

Notes: DBH: diameter at breast height; r: radius.

Source: Prepared by the authors.

FIGURE 20.2

Design of sampling units and plots used to obtain data for the National Forest Inventory



Source: **FAO.** 2008. *Manual de campo del Inventario Nacional Forestal de Nicaragua 2007-2008.* Managua, FAO.

TABLE 20.5

Equations used for volume and biomass calculations

Variable	Equation	Reference
Total volume (m^3)	$\pi / 4 \times DBH^2 \times Ht \times ff$	Prodan (1997)
Biomasa (kg)	Above-ground biomass Natural broadleaved forest CC > 10%: Dry (precipitation < 1 500 mm), climate regions 3, 6, DBH range 5 cm to 40 cm $Y = Exp\ (-1.996 + 2.32 \times Ln\ (DBH))$	Brown (1997)
	Moist (1 500 mm to 4 000 mm), climate regions 1, 2, 4, 5, 7, DBH range 5 cm to 148 cm $Y = Exp\ (-2.134 + 2.530 \times Ln\ (DBH))$	Brown *et al.* (1989)
	Moist (1 500 mm to 4 000 mm), climate regions 5, 7, DBH range 4 cm to 112 cm $Y = 21.298 - 6.953\ (D) + 0.740\ (D2)$	Brown and Iverson (1992)
	Natural coniferous forest CC > 10% Moist (1 500 mm to 4 000 mm), climate regions 1, 2, 4, 5, 7, DBH range 5 cm to 148 cm $Y = Exp\ (-2.289 + 2.649 \times Ln\ (DBH) - 0.021 \times (Ln\ (DBH))^2)$	Brown (1997)
	Use of volume factor, wood density factor and expansion factor for the following: Mangrove forests CC > 10% Planted forests CC > 10% Other natural land with forests CC > 5% Other agroforestry land CC > 5% Other land with few trees CC > 5%	Brown (1997)
	Shade-grown coffee, humid climate region (1 500 mm to 4 000 mm) $Biomass = -0.834 + 2.223(log10DBH)$	Xiao and Ceulemans (2004)
	Pastures with trees, humid climate region (1 500 mm to 4 000 mm) $Log10biomass = -2.18062 + 0.8012\ (DBH) - 0.0006244\ (DBH2)$	Jiménez Ruíz *et al.* (2019)

Notes: CC: canopy cover; DBH: diameter at breast height; ff: form factor; Ht: total height.

Source: **Brown, S.** 1997. *Estimating biomass and biomass change of tropical forest: A primer.* FAO Forestry Paper 134. Rome, FAO.; **Brown, S. & Iverson, L.R.** 1992. Biomass estimates for tropical forests. *World Resource Review*, 4(3): 366–384.; **Brown, S., Gillespie, A.J. & Lugo, A.E.** 1989. Biomass estimation methods for tropical forests with applications to forest inventory data. *Forest Science*, 35(4): 881–902.; **Jiménez Ruíz, E.R., Fonseca González, W. & Pazmiño Pesantez, L.** 2019. Sistemas silvopastoriles y cambio climático: estimación y predicción de biomasa arbórea. *La Granja: Revista de Ciencias de la Vida*, 29(1): 45–55.; **Prodan, M., Peters, R., Cox, F. & Real, P.** 1997. *Mensura forestal*. San José, Inter-American Institute for Cooperation on Agriculture (IICA) and Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ).; **Xiao, C.-W. & Ceulemans, R.** 2004. Allometric relationships for below- and aboveground biomass of young Scots pines. *Forest Ecology and Management*, 203(1–3): 177–186.

Table 20.4 describes the elements quantified at each plot level. Information is recorded in each of the plots on the different types of land use, burned areas, geographical features, trees with a diameter at breast height (DBH) greater than 20 cm in forested areas, trees with a DBH greater than 10 cm in areas outside forests, as well as information on soils and natural regeneration. In addition, people living in the areas being measured are identified and interviewed to obtain information on land tenure, data to determine poverty levels, and other variables of interest to INAFOR. Likewise, in areas with more than 5 percent tree cover and in forests, interviews are conducted with forest resource users.

When the land use is forest, each plot has three nested subplots measuring 10 m by 20 m (NP 1), which are located between 0 m and 10 m, 120 m and 130 m, and 240 m and 250 m from the starting point of the main plot, where trees between 10 cm and 20 cm DBH are measured. In addition, three circular subplots with a radius of 3.99 m (NP 2) are established in order to measure the regeneration of seedlings and saplings. The central point of the first plot is located 5 m from the starting point of the plot and 5 m to the left, the second plot is located 125 m from the starting point and 5 m to the left, and the third plot is located 245 m from the starting point and 5 m to the left.

TABLE 20.6
Results of the 2007–2008 National Forest Inventory

Variable	Result	Description
Land area – Forest (ha)	3 254 144	Total forest area
Land area – Other natural land with trees (ha)	2 219 217	Other land with trees and shrubs
Land area – Other agroforestry land (ha)	2 099 127	Other agroforestry land
Land area – Other land without trees (ha)	4 264 548	Other land without trees
Commercial volume (m^3)	120 000 097	Total area volume
Total number of trees	43 768	Trees inventoried (living and dead)
Biomass (t d.m.)	430 684 691.3	Total biomass (living and dead) in forest areas and outside forests
Carbon (t)	202 432 215.6	Total carbon

Note: t d.m.: tonnes of dry matter.
Source: **INAFOR (National Forestry Institute).** 2009. *Resultados del Inventario Nacional Forestal. Nicaragua, 2007-2008. 2nd Ed.* Managua.

20.5 LAND AREA, VOLUME AND BIOMASS CALCULATIONS

For volume calculations in broadleaved and coniferous forests, general cylinder formulas were used, with a form factor of 0.7 for broadleaved forests and 0.45 for coniferous forests; see equations in Table 20.5.

As regards biomass calculations, these were grouped into forest areas and non-forest areas with woody species. Table 20.5 describes the NFI land use classes and the corresponding methods used.

For the calculation of biomass outside forests, the available information for calculations as well as parameters for estimating biomass were reviewed; few data and parameters were available. Two allometric equations developed in Nicaragua by Xiao and Ceulemans (2004) and Jiménez Ruíz (2019) were used for shade-grown coffee plantations and for pastures with trees. For other uses outside forest areas, it was proposed that calculations use the total volume and basic wood density variables (Table 20.5).

The proportion estimator was used to estimate the area, and the ratio estimator was used to estimate volume and biomass (Cochran, 1977).

20.6 RESULTS OF THE MOST RECENT NATIONAL FOREST INVENTORY

The results of the first 2007–2008 NFI are summarised in Table 20.6. Based on the country's land area, forest cover was estimated at 25 percent of the national territory; of this, 3 180 465 ha are natural forest and 73 679 ha are planted forest. The country has four types of forests (broadleaved, coniferous, mixed and mangrove). The natural broadleaved forest was estimated at 2 760 018 ha and coniferous natural forest at 374 739 ha; the remainder corresponds to mangrove with 28 919 ha and mixed forest with 16 789 ha.

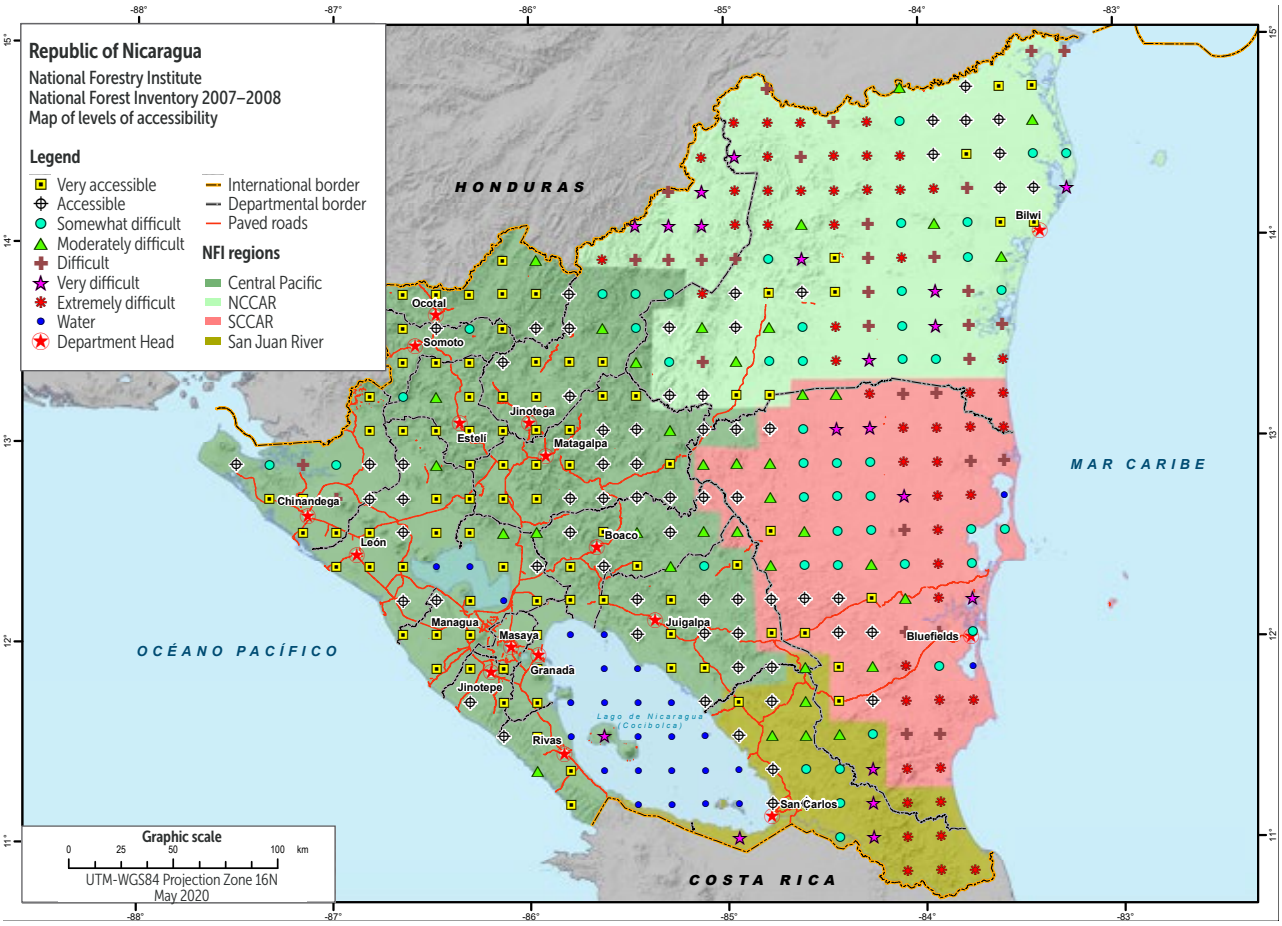
As regards the accuracy of the NFI information (INAFOR, 2009), errors in estimates are a function of the variability of the datasets analysed as they are affected by the number of replicates of each variable in each sample; the greater the number of replicates, the more precise the data.

To determine the sampling error, for an 80 percent confidence level, the standard error is multiplied by 1.3; likewise, for a 90 percent confidence level, the standard error is multiplied by 1.6, and for a 95 percent confidence level, it is multiplied by 2.0.

Following the technical standards for the management of broadleaved forests, a confidence level between 80 percent and 90 percent is required for the presentation of sampling errors. If a 90 percent confidence level is considered, the basal area errors in the different land cover types of the first level of classification (forest, other natural land with trees, and other land) present values of less than 12 percent. For areas of the sample with sparse coverage, where sampling errors may be high, looking for other more reliable sources of information is recommended; if alternative data sources are not available, it is recommended to moderate their use, depending on the risk involved. However, it should be considered that for many variables these are the only existing data.

FIGURE 20.3

Location and accessibility of sampling units by operational region



The boundaries shown and the names and designations used on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any countries, territories, cities, areas, authorities, or delimitation of their frontiers or boundaries. Dotted lines on maps represent approximate boundaries for which there may not yet be full agreement.

Source: **FAO.** 2008. *Manual de campo del Inventario Nacional Forestal de Nicaragua 2007-2008.* Managua, FAO.

20.7 IMPLEMENTATION AND QUALITY CONTROL

The first NFI was implemented through an agreement between INAFOR and FAO. The National Forestry Institute appointed a national coordinator, whose responsibilities included inter-institutional coordination, monitoring and institutional ownership of the activities. In addition, the National Forestry Commission (Comisión Nacional Forestal – CONAFOR, according to its acronym in Spanish) monitored and assessed the NFI process.

A technical unit was established consisting of a coordinator (international consultant) in charge of planning and ensuring the implementation of the NFI, as well as a national consultant responsible for the coordination with other institutions and institutional ownership. The supervision of the technical field teams was supported by three consultants. Technical and administrative assistance was provided by FAO.

For the field survey, the country was divided into four operational regions. Figure 20.3 shows the following distribution: i) Pacific-Central-North; ii) North Caribbean Coast Autonomous Region (NCCAR); iii) South Caribbean Coast Autonomous Region (SCCAR). and iv) San Juan River.

Field measurements were conducted by contracted consultants; 822 people were employed (Table 20.7), of which 92 percent were men and 8 percent were women (INAFOR, 2009). Terms of reference were developed and a public tender process was carried out according to established procedures and standards. The technical field teams consisted of at least five people: a leader, an assistant, an

interviewer and two local guides. A description of roles and responsibilities was prepared for each of the members of the technical field teams. In addition, there were four administrative support staff (two women and two men).

TABLE 20.7

Distribution of 2007–2008 National Forest Inventory staff according to their positions

Position	Women	Men	Total
National Coordinator	-	1	1
Technical Unit Coordinator	1	-	1
Coordination support	4	6	10
Temporary consultants	-	3	3
Leaders	4	24	31
Assistants	8	25	33
Interviewers	7	23	30
Local guides	16	427	443
Local support	26	244	270
Total	66	753	822
Percentage (%)	8	92	100

Source: **INAFOR.** 2009. *Resultados del Inventario Nacional Forestal. Nicaragua, 2007-2008. 2nd Ed.* Managua.

The data collection equipment and technologies used for the field survey included the following: global positioning system (GPS) receiver, tape measure, diameter tape, clinometer, laser distance metre, MP3 recorder, digital camera, alkaline batteries, galvanised tubes, fluorescent vinyl tape, pH tape, first aid kit, torch, hammocks and mobile phone, among others.

All technical teams were trained prior to the start of the fieldwork, based on the field manual. This training was carried out to strengthen the consultants' capacities in taxonomy and tropical dendrology, with the objective of providing a conceptual basis for identifying families of tree species, using dendrological keys, and managing techniques for the collection and preservation of botanical material. The Technical Unit (TU) staff were trained in Geographic Information Systems and database management, with the aim of improving their skills in the use of these tools for the supervision and management of NFI information.

Technical teams were provided assistance for the first SU in the field, in order to ensure that the appropriate knowledge had been acquired during the training sessions. In addition, technical sessions were held with the field teams to respond to problems identified in the field.

Regarding data entry, training was provided on the NFI storage system (SySINF), a software created by the TU and installed on the consultants' computers. The NFI data were recorded in eight field forms to capture the information. The following quality control elements were used for the review and approval of the field information received by the TU:

- Training for all field crews and accompaniment of each crew to the first plot;
- Telephone support to all field crews to resolve any doubts they may have;
- A control sheet to record the entry of the information received;
- Once the documents had been registered and treated as received, the field supervisor was responsible for verifying that the report, the database and the forms were similar to each other. Following the revision of the documents, the field forms were scanned in order to keep a back-up copy in case of loss;
- Any information that presented inconsistencies was returned to the field leader for correction as many times as necessary; alternatively, joint meetings were held with the supervisors to review and correctly enter all the information into the SySINF database, thus ensuring the reliability of data.

The data collected in the field was cleaned and organized before being entered into SySINF. Once the data entry was completed, it was backed up and sent to the TU for review and approval.

The next step was to validate and verify that the database was consistent and coherent, through new field visits, expert opinions, cross-listing of species, among others. Afterwards, data was processed and analysed, providing inputs for the preparation of the first NFI document.

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For the implementation of the second NFI measurement cycle, INAFOR has decided to conduct this work using its own personnel. Considering a five-year cycle (2022–2026), 20 percent will be conducted each year, with approximately 69 SUs to be surveyed annually (excluding water bodies). Each annual sampling is referred to as a panel or campaign. The panel design allows a portion of the SUs to be remeasured each year in such a way that the entire continental territory of Nicaragua is covered during the established period.

The 69 SUs measured annually will be distributed to each area of the departmental and subregional delegations of INAFOR, which will allow for easy distribution of budgets and human resources. To manage the operations of the second NFI, a Forest Monitoring and Information Directorate was created, which will be responsible for monitoring and supervision.

Furthermore, for the implementation of the second NFI measurement cycle, the sampling intensity and the design of the measurement plots should be reviewed in accordance with the objectives and indicators, and in harmony with the land use and land cover categories used in the reference level of forest emissions and the NGGI.

20.8 OTHER RELEVANT VARIABLES COLLECTED

The first NFI collected information not only on forests, but also areas outside forests with or without trees. This was done in order to monitor forest resources on land that is being used for livestock farming, but that still has remnants of natural forests or that can be improved to create agroforestry and silvopastoral systems.

The information recorded in the NFI is grouped into the following themes and variables:

- forest cover and deforestation dynamics;
- forest condition, health and vitality;
- forest management;
- productive status of natural forests;
- plantation coverage, status of agroforestry systems and trees outside forests;
- information on environmental and conservation functions of forests;
- forest heritage of the country's commercial volume;
- socioeconomic information on forests and trees outside forests.

The NFI also collected socioeconomic information on the labour invested in productive and domestic activities, considering four categories of age/sex (women, men, girls, boys) and the main activities practised (agriculture, forestry, mining, domestic activities, etc.). The objective was to understand the relative importance of each activity according to age and sex (INAFOR, 2009).

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20.9 FUTURE PROSPECTS

Within the framework of the REDD+ mechanism, Nicaragua will implement a National measurement, reporting and verification System for the collection and processing of information on forest cover and biomass, obtained through remote sensing and NFI field measurements. This information will be used for periodic estimates of emissions and reductions in order to perform regular assessments of indicators for compliance with safeguards, as well as to monitor alternative benefits. The MRV system establishes a platform where national institutions, regional governments, Indigenous and territorial communities will contribute with monitoring results, protocols for estimates and geographic information, all of which will be accessible to the general public.

The system is composed of three submodules:

- The Carbon Module will measure, monitor, report and verify the status and condition of Nicaragua's forests, as well as deforestation and forest restoration. It will report on avoided emissions, as well as those occurring due to changes in carbon stock at the national level.
- The Multiple Benefits Module will monitor the indicators related to biodiversity and food security.
- The Safeguards Module will provide and manage information related to the application of safeguards.

In 2015 and recently in 2019, with the assistance of the National Avoided Deforestation Strategy programme (Estrategia Nacional para la Deforestación Evitada – ENDE-REDD+, according to its acronym in Spanish), a total of 110 SUs were measured with the aim of updating emission and removal factors. In addition, allometric equations calibrated with national data are expected to be developed prior to the first monitoring event under the Emission Reduction Payment Agreement.

The removal factors express the annual growth of new forests in tonnes of carbon dioxide per hectare. The NFI database does not account for the growth rates of biomass in Nicaraguan forests; its calculation is based on literature on forest regeneration in Nicaragua. There is no published information available regarding the average annual increase of forest biomass in Nicaragua. Therefore, national studies are intended to be carried out on the calculation of growth rates based on emission factors derived from the NFI database for stable forests.

Within the MRV system, INAFOR is in charge of the implementation of the NFI, whose data serve as the basis to estimate the carbon density of different land uses (including "non-forest" uses) expressed in emission factors.

With the assistance of FAO, Nicaragua will hold consultation workshops with national experts and other stakeholders involved in forestry, with the aim of reaching a consensus on new designs and methodological alternatives for forest inventories that have been tested in neighbouring countries, such as Costa Rica and Honduras. The workshops will be designed to respond to information needs on the state of forests; once defined, these will be duly validated in the field for their potential inclusion in subsequent NFI cycles (FAO and INAFOR, 2019).

The NFI is currently in the process of being updated. Through INAFOR, Nicaragua will start a monitoring process of all forested areas in 2022, using national funding sources. With a sampling intensity of 20.0% (69 SUs) in the national territory, this monitoring process will have a multipurpose approach. That is, it will seek to assess the state of forests subject to the harvesting of non-wood forest products (resin); and institutionalize the NFI through capacity development of its technical staff at the central and territorial levels, together with fostering ownership in the application of the current methodology and design for the proper collection and continuous (annual) updating of data.

In addition to establishing the basis for a national study on the existence and population distribution of the species *Dalbergia retusa* through the collection of field data – in compliance with Resolution Conference 12.8 (Rev. CoP17) on Review of Significant Trade in specimens of Appendix II species (INAFOR and MARENA, 2017), requested by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) – this monitoring is intended to be expanded and carried out annually for other commercially valuable tree species, for example, Atlantic mahogany (*Swietenia macrophylla*).

Likewise, in order to make technical improvements in NFI data collection, the following should be considered: adaptation of digital technologies (drones, Lidar sensors, hardware and software), tablets and/or GPS receivers with the capacity to feed field forms and generate their respective databases for the subsequent processing and analysis of results, making use of programmes designed for this purpose, for example, SilvaMetricus.

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NEXT CHAPTER

PANAMA

Chapter 24

PANAMA

NATIONAL FOREST INVENTORY OF PANAMA

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21.1 HISTORICAL OVERVIEW OF NATIONAL FOREST INVENTORIES IN PANAMA

The Republic of Panama is located in south-eastern Central America, between 7°12'07" and 9°38'46" north latitude and 77°09'24" and 83°03'07" west longitude. It has an area of 75 517 square kilometres (km²). Historically, the few national forest inventories conducted in the country have been carried out at relatively long intervals. The first national forest inventory was conducted during the period 1968–1972, with support from the Food and Agriculture Organization of the United Nations (FAO). The aim was to recognise forest formations and record the stock of timber species with a view to forest harvesting, thus establishing a basic forest policy and administration. After more than 40 years since this national forest inventory was conducted, the updating of information on the country's forests has begun by means of a national forest inventory.

In recent years, national forest inventories around the world have incorporated novel approaches, which have broadened the type of information they provide. These inventories are now multipurpose, providing a detailed description of forests, their biophysical and ecological characteristics, and socioeconomic aspects related to the use of the products and services they provide (Melgarejo, Calderón and Ruiz, 2015).

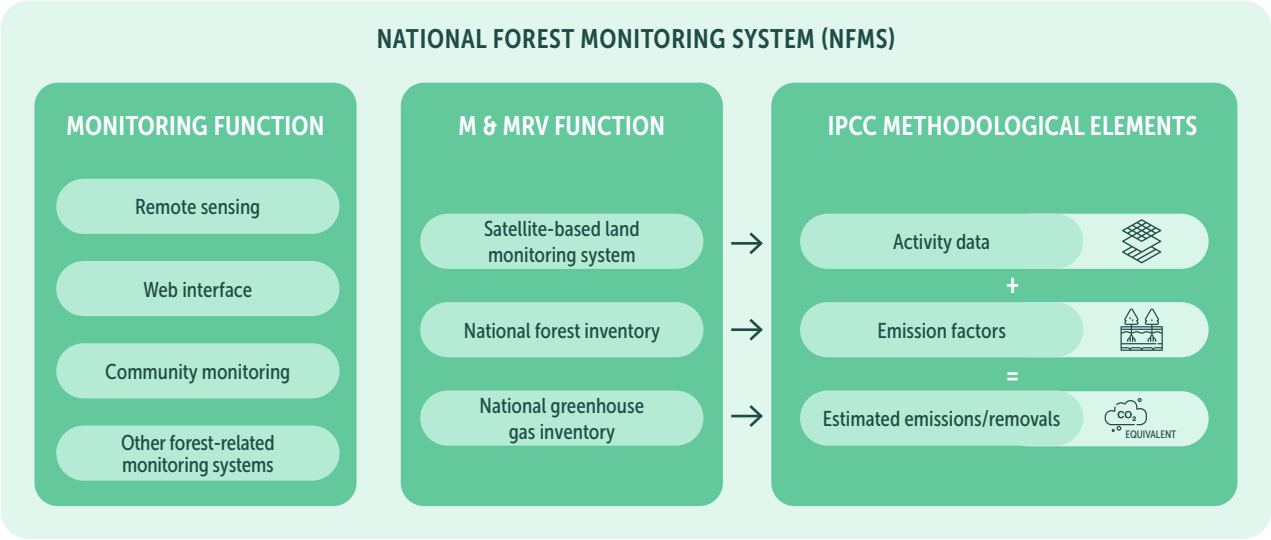
In 2008, Panama expressed its interest in joining the initiative that gave rise to the Reducing Emissions from Deforestation and Forest Degradation (REDD+) mechanism. Consequently, since January 2011, the country has benefited from the cooperation of the United Nations REDD+ (UN-REDD) programme through the implementation of a national programme (UN-REDD Panama), which aims to assist the country in the REDD+ readiness process (Melgarejo, Calderón and Ruiz, 2015). In this context, as described by Melgarejo, Calderón and Ruiz (2015), various decisions and recommendations of the Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) indicate that an important component for REDD+ is the establishment of a National Forest Monitoring System (NFMS), which should be based on a combination of remote sensing and field measurements to estimate and report greenhouse gas emissions and removals from forests.

According to the Intergovernmental Panel on Climate Change (IPCC) (2006), there are two distinct methods for estimating emissions from sources and removals by carbon sinks related to the annual rates of change in all forest carbon pools:

- stock change method: estimates annual net emissions and removals based on the difference between total carbon stocks at two given points in time, divided by the number of years elapsed (see equation 3.1.2 in IPCC [2003] or equation 2.8 in IPCC [2006]);

FIGURE 21.1

Outline of the National Forest Monitoring System and methodological elements for estimating carbon dioxide emissions/removals



Note: IPCC: Intergovernmental Panel on Climate Change; M: monitoring; MRV: measurement, reporting and verification
Source: **Melgarejo, C., Corro, V., Ruiz, M.d.C., Calderón, A. & Sánchez de Stapf, M.** 2015. *Inventario Nacional Forestal y de Carbono de Panamá: Resultados de la Fase Piloto 2013-2015.* Panama City, Ministry of the Environment and UN-REDD.

- gain-loss method: estimates annual net carbon dioxide (CO_2) emissions or removals as the sum of gains and losses in carbon pools (see equation 3.1.1 in IPCC [2003] or equation 2.7 in IPCC [2006]).

For FAO (2018), the first method is suitable for estimating carbon stocks, typically from repeated field measurements of forest variables as part of a national forest inventory or as survey data. In such cases, remote sensing outputs are useful for improving sampling in a national forest inventory, as they contribute to stratification processes and provide complementary data during estimates that can enable the identification of REDD+ activities.

Considering the requirements of the REDD+ mechanism and certain institutional needs, the Ministry of the Environment of Panama (MiAMBIENTE) decided to implement a National Forest and Carbon Inventory (NFCI) as a national priority for REDD+, using resources from the UN-REDD Panama programme, in order to lay the foundation for the development of a NFMS (Figure 21.1), thereby providing information on national emission factors.

A brief summary to provide a better understanding of the NFCI results is presented below.

Through a process of dialogue, MiAMBIENTE defined the scope of the NFCI as follows:

- *geographic: national level;*
- *thematic: multipurpose, addressing not only the requirements for REDD+, but also information needs to support the formulation and monitoring of the country's sustainable forest policy and management;*
- *timeframe: continuous with permanent sampling units to better assess changes and forest dynamics (Melgarejo, Calderón and Ruiz, 2015, p. 6).*

The NFCI started with a pilot inventory that focused on the following specific objectives:

- *obtain information on the natural variability of key indicators;*
- *determine costs and timing of different tasks and activities;*
- *test and improve the methodology developed for the fieldwork, database, forms and field manuals, and organize the work and related logistics;*

TABLE 21.1

Historical overview of national forest inventories in Panama

Inventory cycle	Implementation period	Scale	Sampling design	Number of sampling units
NFI1	1968–1972	National	Two-stage systematic stratified	
			The sampling frame for this inventory was a 5 km by 5 km grid of points, where primary sampling units (SUs) were systematically distributed in six strata consisting of bio-ecological zones. In each primary SU, two secondary SUs measuring 25 m wide by 5 km long were incorporated. The plots were 10 m by 200 m in five of the strata, and a 0.5 ha circular plot was used in one stratum (FAO and UNDP, 1972).	The survey rate ranged from a minimum of 0.03% to a maximum of 0.18% of the land area of the strata (FAO and UNDP, 1972).
NFCI1	2013–2018	National	Systematic stratified	
			Pilot inventory: the sampling frame used for the pilot inventory consisted of a grid of points that were numbered every 3 km by 3 km, covering the entire national territory; the stratification for this phase was conducted taking into consideration the grid of potential points to be sampled in forest and non-forest areas, based on the 2012 land cover and land use map (Melgarejo, Calderón and Ruiz, 2015).	Pilot inventory: 50 SUs were selected, of which 36 SUs were measured.
			In the next NFCI stage, the grid of numbered points and the 2012 land cover and land use map were used to carry out a stratification, grouping the SUs of the grid into five main categories: forest, mangrove, agricultural and livestock, fallow and other uses (Rodríguez and Corro, 2021).	Based on the information from the pilot phase, the sample size was increased to 92 SUs. Of these, 87 SUs were measured (Rodríguez and Corro, 2021).
NFCI2	2021 – in progress	National	Systematic stratified	
			For the second NFCI cycle, the sample coverage within the strata was expanded to include attributes that were not recorded during the first cycle. The five strata were maintained and the SUs were redesigned (Rodríguez and Corro, 2021).	150 SUs (Rodríguez and Corro, 2021)

Source: **FAO & UNDP.** 1972. *Inventariación y demostraciones forestales – Panamá. Reconocimiento general de los bosques y inventario detallado de Azuero. I – Método y realización de los inventarios.* Rome, FAO.; **Melgarejo, C., Calderón, C., & Ruiz, M.d.C.** 2015. *Inventario Nacional Forestal y de Carbono de Panamá: Diseño de la Fase Piloto 2013-2015 y Propuesta para la Fase Final.* Panama City, Ministry of the Environment and FAO.; **Rodríguez, E. & Corro, V.** 2021. *Inventario Nacional Forestal y de Carbono de Panamá: Diseño de la segunda mensura 2021-2025.* Panama City, Ministry of the Environment.

- *train technicians and professionals from MIAMBIENTE, forestry consultants, non-governmental organizations and Indigenous Peoples in the proposed methodology for field data collection (Melgarejo, Calderón and Ruiz, 2015, p. 6).*

The design of the final inventory was based on the results of the pilot inventory. It consisted of a stratified systematic design with five strata: forest, mangrove, fallow, agricultural and livestock use, and other uses. The 2012 land cover and land use map was used for the stratification process. A 3 km by 3 km grid of points, covering the entire national territory, was developed for the forest inventory; in each point the type of land cover were filtered. The results obtained from this inventory were used to estimate the areas and emission factors, among other variables.

During 2020 and early 2021, the Forestry Directorate, within MiAMBIENTE, improved the sampling design used in the first cycle of the inventory, with the aim of expanding the coverage of the sampling units (SUs) for certain attributes that were not adequately represented in the design of the first cycle. Details of this new inventory design are presented at the end of this chapter.

The cycle of Panama's national forest inventories that began in 1968 is summarised in Table 21.1.

TABLE 21.2

Summary of definitions used in the National Forest and Carbon Inventory

Term	Definition	Variables and thresholds
Forest	Land extending over 0.5 ha, with trees of an average height of 5 m or more, a canopy cover of 30% or more, or trees capable of reaching these thresholds *in situ*, provided that the land has been declared for forest restoration, conservation and/or management purposes. In the last case, in areas where abiotic conditions prevent trees from reaching 5 m *in situ*, it is sufficient for them to exceed 30% canopy cover. It does not include land under predominantly agricultural or urban use (ANAM and UN-REDD Programme, 2014). Other vegetation formations: – Linear tree structures (gallery forest and windbreaks): classified as forest when they meet the criteria of land area, height and canopy cover and are wider than 20 m, based on canopy projection. – Palm formations: semi-natural stands of coconut palm associated with other vegetation are classified as mixed broadleaved forest and mature/secondary criteria apply; planted palm stands should be classified as permanent crops. – Fallow: generally classified as shrubby and herbaceous vegetation with the exception of fallow that has been declared for forestry use, which is classified as forest (ANAM and UN-REDD Programme, 2014).	Minimum area: 0.5 ha Canopy cover: ≥ 30% Tree height: ≥ 5 m *in situ* Minimum width: 20 m, criteria to define gallery forests Exceptions: explained in the definition
Volume	Total volume (m^3): living trees with diameter at breast height (DBH) equal to or greater than 10 cm. Includes bark (Melgarejo *et al.*, 2015).	Minimum diameter (DBH to 1.30 m high): ≥ 10 cm Includes stump Includes bark Commercial height: from the base to the first branch or fork Groups of species: all species identified in the field and sample collection
Biomass	Above-ground biomass: dry biomass (kg) of living trees with DBH equal to or greater than 10 cm. Below-ground biomass: not measured. Necromass: dry biomass of dead litter material and lying cylindrical and semi-cylindrical dead wood from stems and branches with a minimum diameter of 5 cm (Melgarejo *et al.*, 2015).	Above-ground biomass DBH: ≥ 10 cm Necromass Minimum diameter of lying dead wood: 5 cm Stumps: not included Standing dead trees: not included Litter included, with minimum sieved diameter not described

Source: **ANAM & UN-REDD Programme.** 2014. *Sistema de clasificación de la cobertura y uso de la tierra para el Sistema Nacional de Monitoreo de los Bosques.* Panama City.; **Melgarejo, C., Calderón, C., & Ruiz, M.d.C.** 2015. *Inventario Nacional Forestal y de Carbono de Panamá: Diseño de la Fase Piloto 2013-2015 y Propuesta para la Fase Final.* Panama City, Ministry of the Environment and FAO.

21.2 TERMS AND DEFINITIONS RELEVANT TO THE IMPLEMENTATION OF THE LATEST NATIONAL FOREST AND CARBON INVENTORY

A land cover and land use classification system was developed in order to establish the NFMS. This process resulted in a hierarchical, coherent system with precise definitions of the national categories and aligned with the main categories established by the IPCC. The definition of forest is an essential element for this system, considering that the country must specify the definition of forest used when it reports to the UNFCCC. Following an extensive process of consultation and debate, and a final review by MiAMBIENTE, it was decided to use the definition of forest presented in Table 21.2, which also provides other definitions of interest for the forest inventory.

21.3 SAMPLING DESIGN

In order to develop an efficient NFCI design, prior information on the variability of different key parameters within and between the different strata is required. Information on the time and cost required for collecting field data is also necessary. In addition, the scope of the inventory should be established, either in terms of the desired level of uncertainty for the key information, or in terms of available financial resources.

In the case of Panama, no previous information was available. It was therefore decided to use funding from the UN-REDD programme to conduct a pilot inventory to generate the required information, and to develop the inventory design based on the information available in the 2012 land cover and land use map. The development of this map had taken into account a land cover and land use classification system that would facilitate the objective identification of thematic categories both in satellite images and in the field (ANAM and UN-REDD, 2014); at the same time, this system would allow the user to utilise the aggregated information at any of its four hierarchical levels. The result was a multipurpose map with a large number of thematic categories, and with a target scale of 1:50 000 and a minimum mapping unit of 1 ha (Figure 21.2).

The agreed design for this pilot inventory was systematic stratified, with two strata: one in forested areas and the other in non-forested areas. To carry out the stratification, a 3 km by 3 km grid of points covering the entire national territory was used, together with the 2012 land cover and land use map.

For this pilot phase, the following elements were considered of utmost importance:

- organization and institutional links;
- sampling unit configuration;
- plot shape and size;
- information to be collected and measurement protocols.

The pilot inventory carried out the first field measurement of 36 SUs out of 50 SUs that had been previously selected. The SUs were selected systematically. The data from the first measurement were used as a pre-sample to determine the final design of the first NFCI survey; this final design was systematic stratified, increased the number of strata up to five, and the SUs were distributed throughout the national territory with nonproportional intensity.

It was initially estimated that 82 SUs would be needed; 10 SUs were subsequently added to this amount as a result of the analysis of the strata, which considered intensification criteria by means of proportionality and the Neyman allocation method, totalling 92 SUs. The number of SUs for the five strata is shown in Table 21.3.

The distribution of the 50 SUs selected for the pilot phase, indicating those that were measured and those that could not be measured, can be seen in Figure 21.3.

TABLE 21.3

Sampling units of the first cycle of the National Forest and Carbon Inventory

Number of sampling units			
Strata	Stratified pre-sampling	Additional sampling	Total
Forest	24	22	46
Agricultural use	8	18	26
Mangrove	2	4	6
Fallow	2	10	12
Other land cover/land use	0	2	2
Total	**36**	**56**	**92**

Source: Prepared by the authors.

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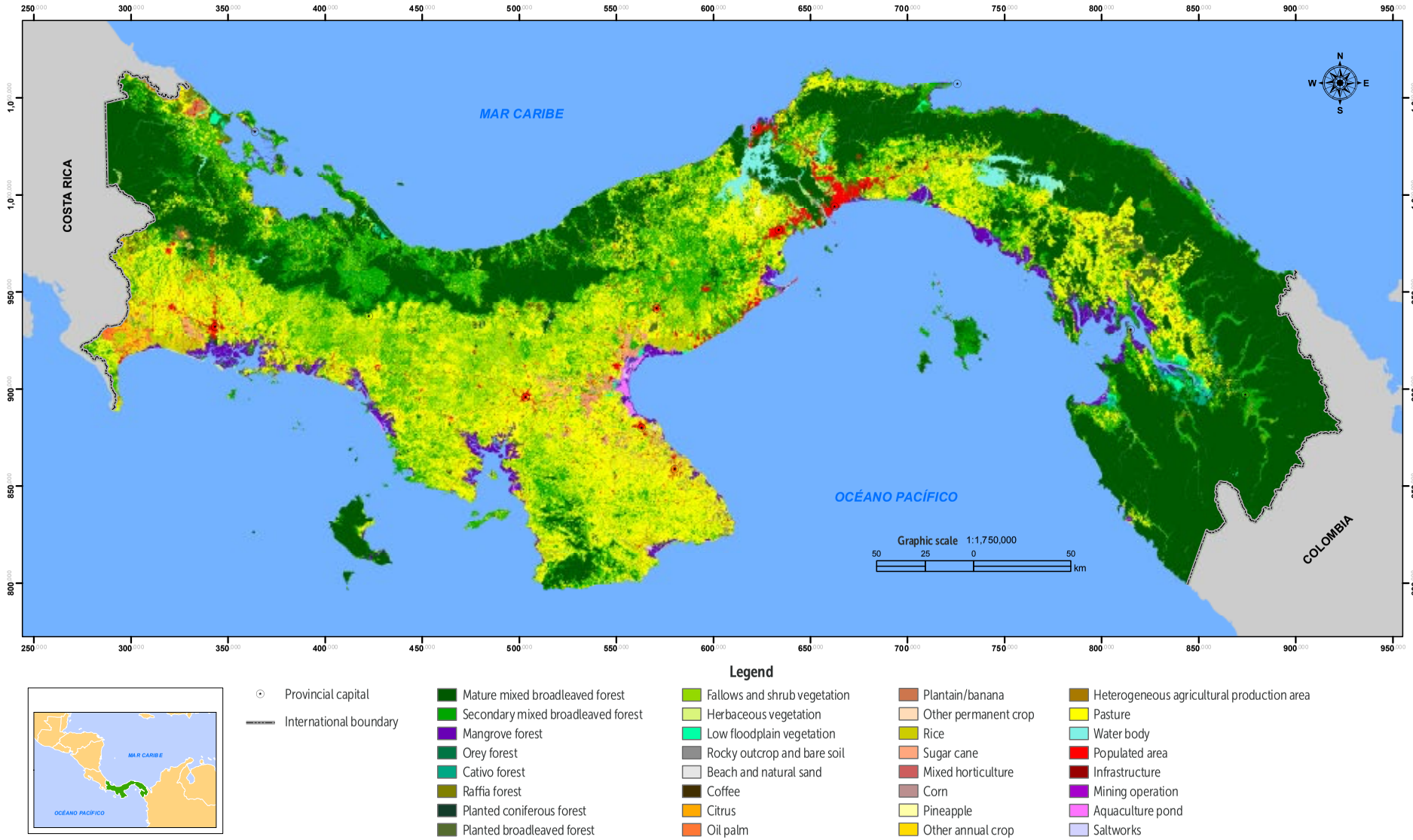
FIGURE 21.2

Map of the distribution of forest types in Panama

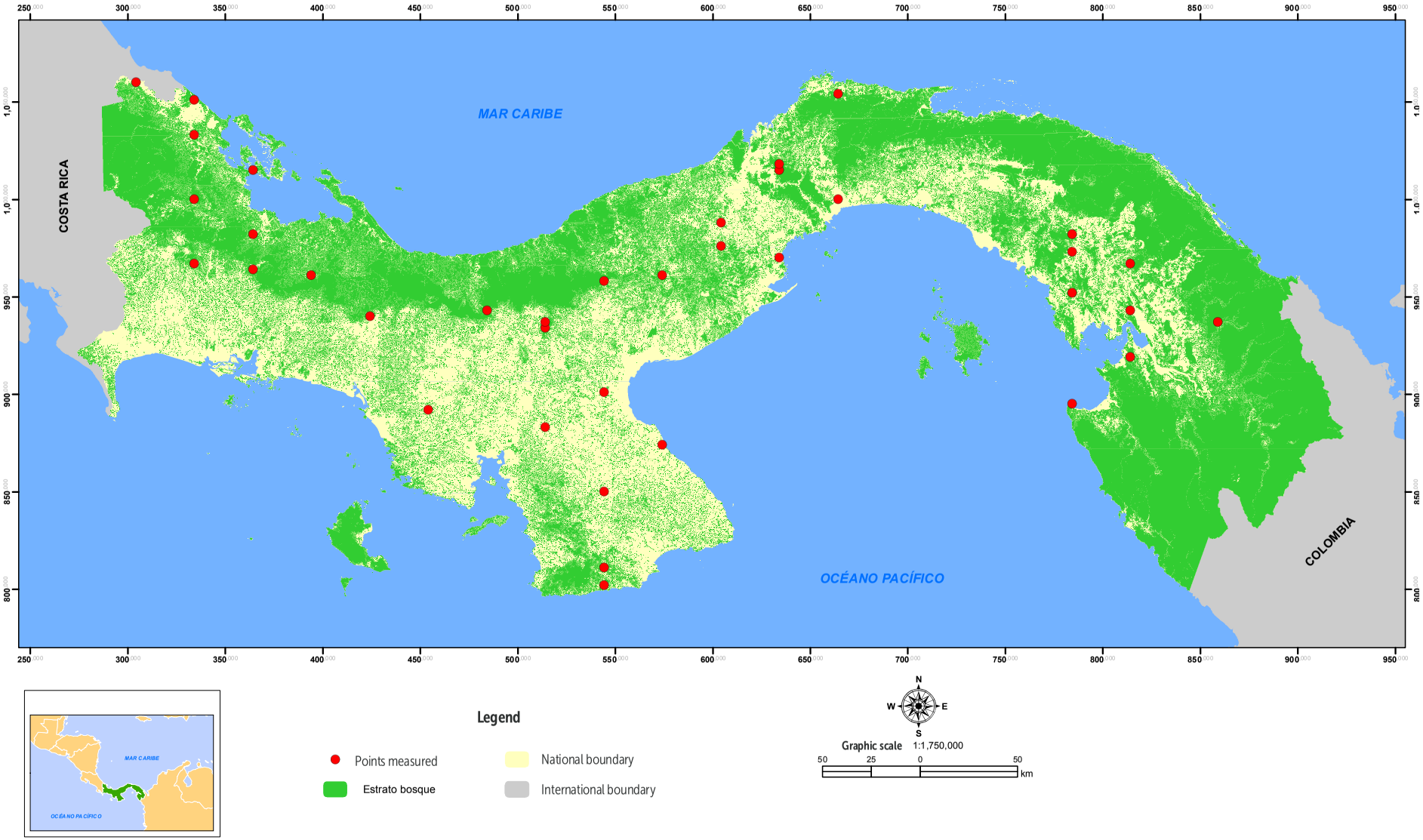


The boundaries shown and the names and designations used on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any countries, territories, cities, areas, authorities, or delimitation of their frontiers or boundaries. Dotted lines on maps represent approximate boundaries for which there may not yet be full agreement.

Source: **Castillo, M., Samaniego, R. & Kindgard, A.** 2015. *Mapa de cobertura y uso de la tierra 2012.* Panama City, Ministry of the Environment and UN-REDD programme.

FIGURE 21.3

Sampling points in the pilot phase of the National Forest and Carbon Inventory of Panama

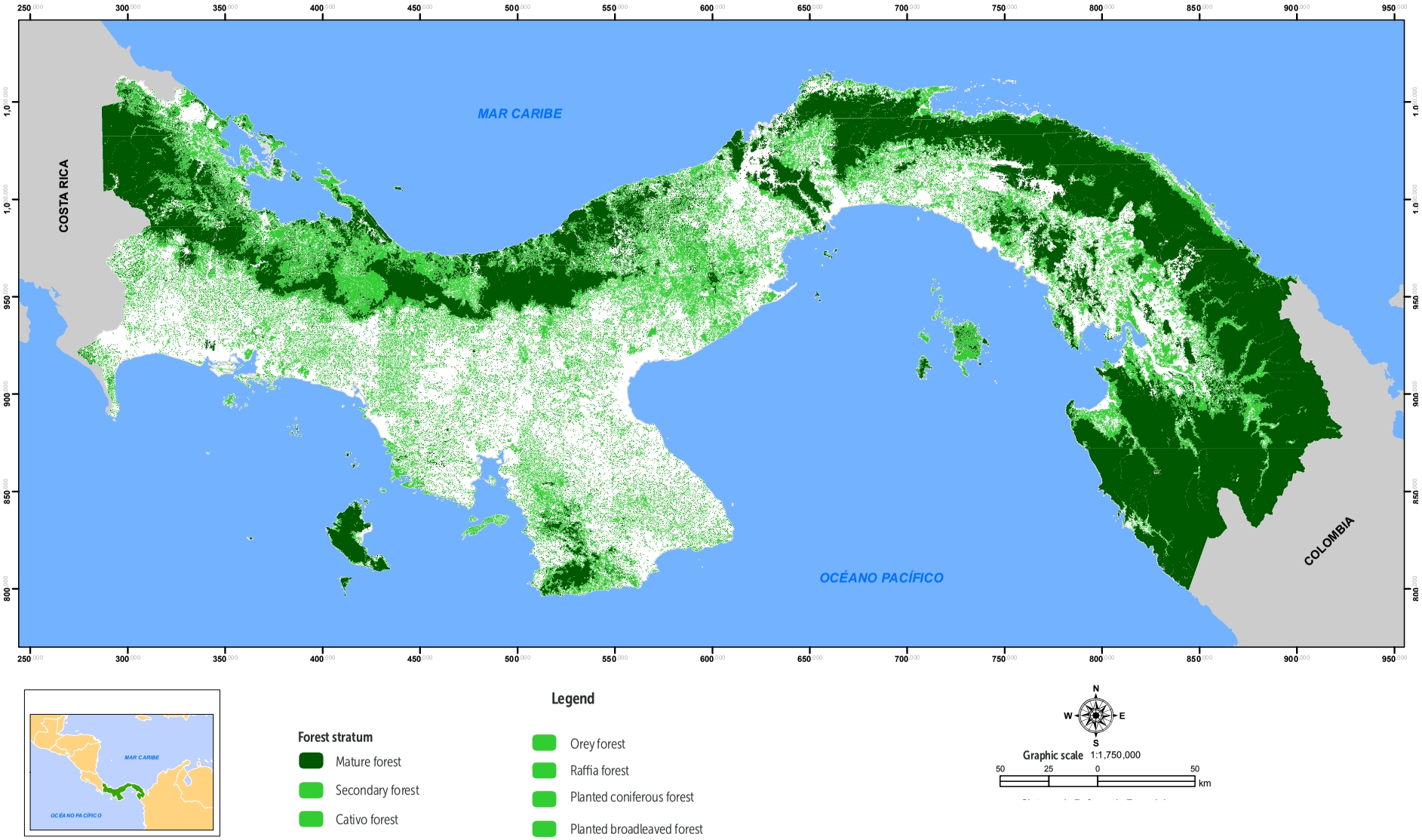


The boundaries shown and the names and designations used on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any countries, territories, cities, areas, authorities, or delimitation of their frontiers or boundaries. Dotted lines on maps represent approximate boundaries for which there may not yet be full agreement.

Source: **MiAMBIENTE.** 2021b. *Cobertura de bosque nacional – Mapa 2012*. (Unpublished). Panama City.

FIGURE 21.4

Forest stratum, grouping the sampling units into the forest categories of the 2012 land cover and land use map



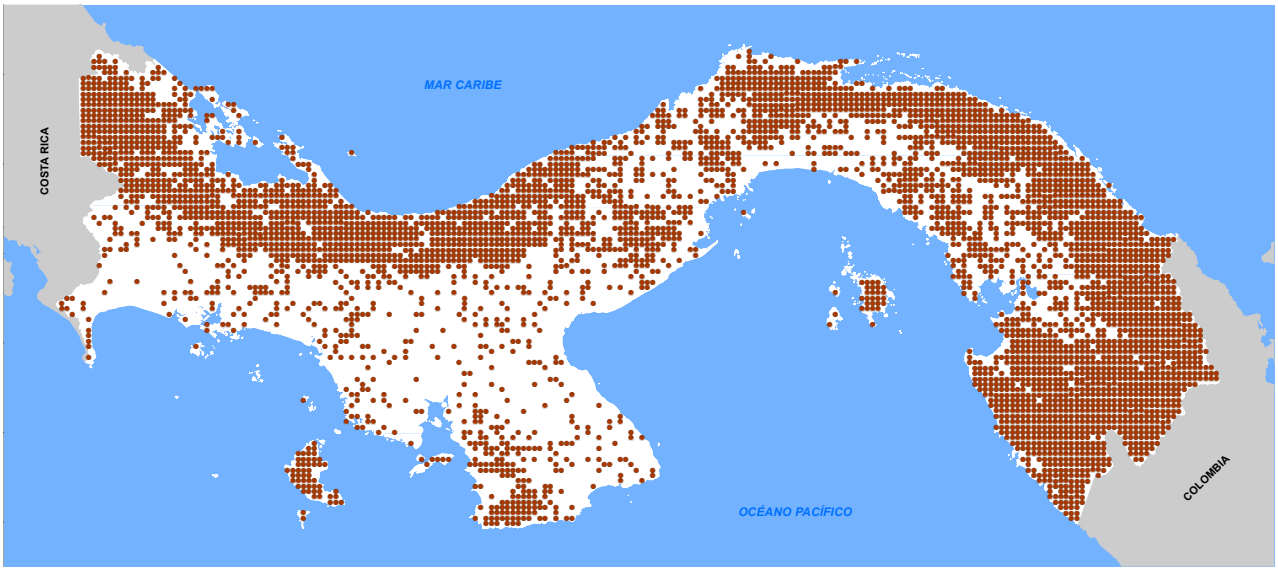
The boundaries shown and the names and designations used on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any countries, territories, cities, areas, authorities, or delimitation of their frontiers or boundaries. Dotted lines on maps represent approximate boundaries for which there may not yet be full agreement.

Source: **MiAMBIENTE.** 2021b. *Cobertura de bosque nacional – Mapa 2012.* (Unpublished). Panama City.

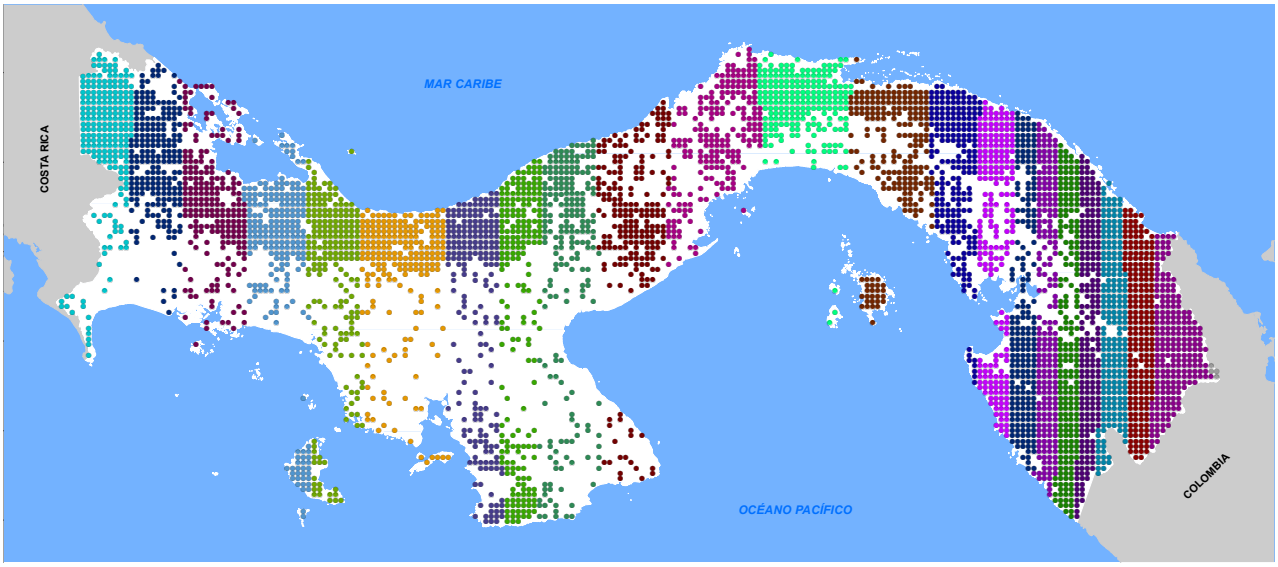
FIGURE 21.5

a) Grid of filtered sampling units and (b) 22 blocks for the selection of samples for the forest stratum

A) GRID OF SAMPLING UNITS FOR FOREST STRATUM – 2012 MAP



B) 22 BLOCKS FOR FOREST STRATUM – 2012 MAP



The boundaries shown and the names and designations used on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any countries, territories, cities, areas, authorities, or delimitation of their frontiers or boundaries. Dotted lines on maps represent approximate boundaries for which there may not yet be full agreement.

Source: **MiAMBIENTE.** 2021c. *Red de unidades de muestreo para el estrato bosque – Mapa 2012.* (Unpublished). Panama City.; **MiAMBIENTE.** 2021d. *Bloques para el estrato de bosque – Mapa 2012.* (Unpublished). Panama City.

To determine the different strata, all SUs were filtered into the corresponding categories of the 2012 land cover and land use map (Jiménez, 2016; Rodríguez and Corro, 2021). As a result, according to Jiménez (2016) for the forest stratum, all SUs were filtered into the forest categories of the 2012 map (Figure 21.4).

The total number of potential SUs to be measured in the forest stratum at national level was then divided by the number of samples to be selected, to obtain 22 blocks in the forest stratum, each with 219 representative SU points.

Within each block, the final SUs were randomly selected, which allowed for a homogeneous distribution throughout the country (Jiménez, 2016), as shown in Figure 21.5. For the selection of the SUs, an automatic procedure was used through the vector research and random selection tool provided by the free software QGIS (Jiménez, 2016).

Once the procedure for the forest stratum was completed, the methodology used for stratification and sample selection was applied to the remaining strata: fallow, agricultural and livestock use, mangroves, and other uses.

21.4 SAMPLING UNIT DESIGN

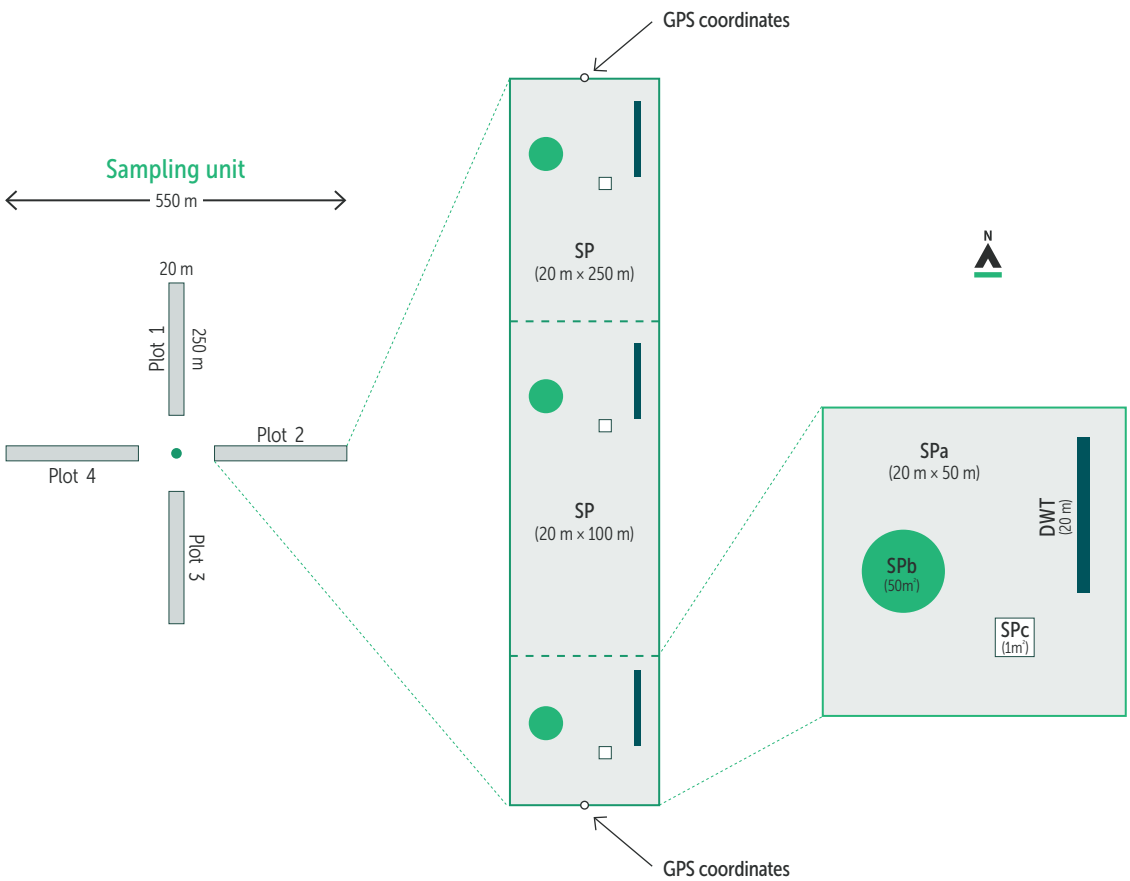
The design of the field measurement plot for the permanent SUs of the NFCI has varied between the first and second measurement cycle, with the aim of adapting data collection to the needs that arise in the process of continuously improving information production. The designs developed are presented below.

21.4.1. FIRST CYCLE

According to Melgarejo, Calderón and Ruiz (2015), during the pilot phase, the SUs were established as permanent. The SU consisted of a cluster with four 20 m by 250 m cross-shaped plots, with each plot equidistant at 25 m from the centre point. The plots were subdivided into three segments (subplots) to measure the different diameter classes of the trees: one subplot measuring 20 m by 250 m for diameters greater than 50 cm, one 20 m by 100 m subplot for diameters greater than 20 cm, and one 20 m by 50 m subplot for diameters greater than 10 cm. In addition, the plots had three subplots with an area of 50 m² to measure regeneration, three 1 m² subplots to measure litter, and three linear transects 20 m in length to measure lying dead wood (Figure 21.6).

This design, which was used for data collection during the pilot inventory, was maintained during the final phase of the first NFCI cycle. In all SUs, trees, litter, lying dead wood and soil were measured and observations were made on land use, forest degradation status and other environmental variables, as well as socioeconomic information.

FIGURE 21.6
Sampling unit and subplot design



Note: GPS: global positioning system; SP: subplot; DWT: dead wood transect.
Source: **Melgarejo, C., Calderón, C., & Ruiz, M.d.C.** 2015. *Inventario Nacional Forestal y de Carbono de Panamá: Diseño de la Fase Piloto 2013-2015 y Propuesta para la Fase Final.* Panama City, Ministry of the Environment and FAO.

21.4.2. SECOND CYCLE

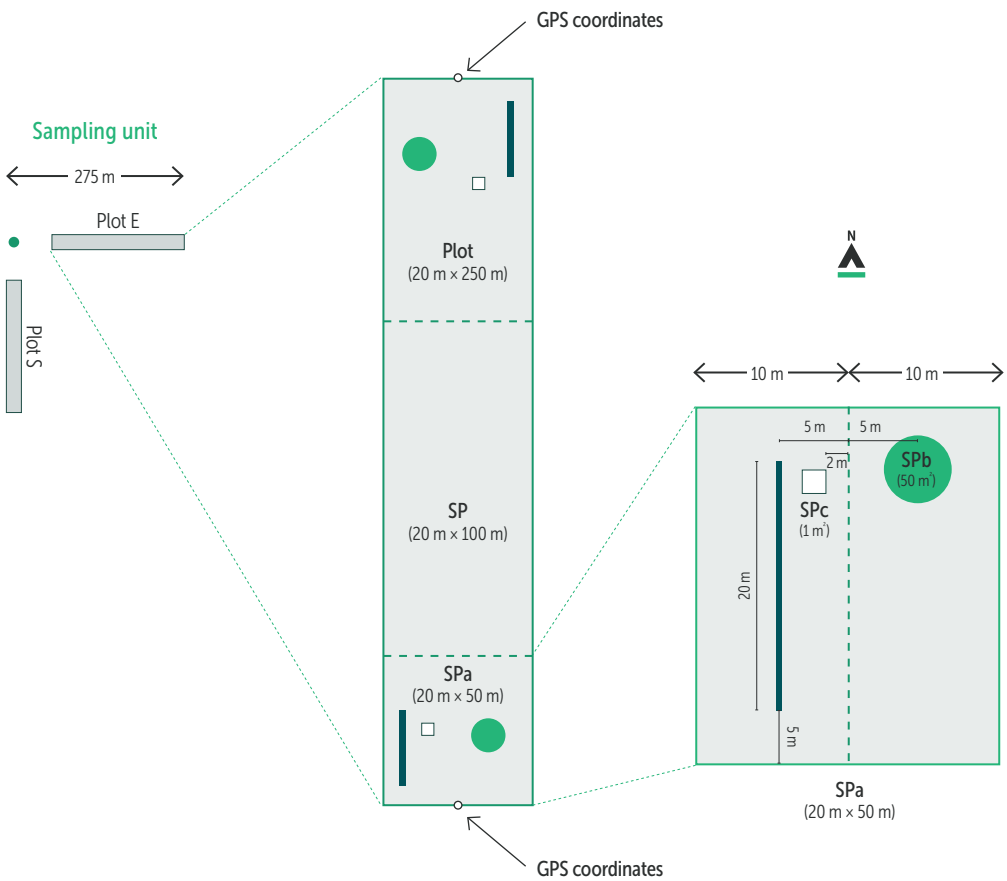
In order to broaden the representativeness of the different types of forest cover and land use, as well as the various related attributes, the number of samples in the forest inventory strata was increased. To this end, the four plots of the cluster plot used in the original SU design were assessed to find the plots with the lowest overall variation in the data. Following the evaluation, a one-hectare SU was selected, consisting of the east- and south-facing plots in the original SU.

The selected subplots were slightly modified from the original design. The modifications made were related to the data collected on natural regeneration, leaf litter and necromass; the data collection was reduced to two points out of three, eliminating the measurement point in the 20 m by 100 m subplot and collecting these data from the left or right side of each subplot, as indicated in Figure 21.7. For the subplot measurements, the same procedure used during the first survey was repeated.

This design, which is in its final stages of discussion with Forestry Directorate and NFCI staff, will increase the total number of SUs to 150, which will be distributed throughout the country (with a sampling error of approximately 15% for above-ground biomass).

FIGURE 21.7

Detail of the proposed design of the sampling unit, plots and subplots to remeasure the National Forest and Carbon Inventory



Note: GPS: global positioning system; SP: subplot.
Source: **Rodríguez, E. & Corro, V.** 2021. *Inventario Nacional Forestal y de Carbono de Panamá: Diseño de la segunda mensura 2021-2025.* Panama City, Ministry of the Environment.

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21.5 LAND AREA, VOLUME AND BIOMASS CALCULATION

The NFCI included measurements in each SU to estimate the five carbon pools, socioeconomic information on the village of influence and topographic characteristics. A measurement protocol was developed for each parameter that was recorded; in addition, fieldwork included remeasuring 20 percent of the SUs to verify the quality of the data that had been collected (Melgarejo, Calderón and Ruiz, 2015).

During the NFCI, the diameter at breast height (DBH), at a height of 1.30 m, was measured with a diameter tape and the height of all trees greater than or equal to 50 cm DBH was measured with a hypsometer. For trees with a DBH between 10 cm and 49.9 cm, height was measured every 10 trees, and for the remaining trees, it was estimated with the naked eye (Melgarejo, Calderón and Ruiz, 2015).

The global positioning system (GPS) was used to locate the central point of the SU and the start and end points of each plot, and a compass was used to maintain the direction of each plot, confirming it every 50 m with the GPS. Distances were taken with a measuring tape, applying a slope correction in the SUs that required it.

The field data was stored in an SQL Server database that was specifically designed for the NFCI data structure. The calculation procedures for intermediate or derived variables such as volume, biomass, carbon, among others, were stored there (Calderón and Calderón, 2020).

The sketch method was used in the calculation of areas according to the land use class (LUC) because of its greater precision. This method consists of drawing a sketch of the plot with the boundaries of each type of LUC. In addition, to calculate the emission factors with the NFCI data, the calculation method based on Double Stratified Sampling in the Silva Metricus software was used (Calderón and Calderón, 2020).

During the fieldwork process, some of the SUs were not measured in the final inventory because of their inaccessibility, either due to their topography or to the owners' refusal to participate in the activity. As a result, these SUs were not considered in the calculations and emission factors were calculated for 87 SUs.

TABLE 21.4

Equations used for volume and biomass calculations

Variables	Equation	Reference
Total volume (m^3)	$Vtot = g \times h \times f$ Where: *Vtot*: total tree stem volume (m^3) *g*: tree basal area (m^2) *h*: total tree height (m) *f*: form factor as per stem quality: – Stem quality A: $f = 0.68$ – Stem quality B: $f = 0.50$ – Stem quality C: $f = 0.40$	Resolution No. AG-0168-2007 (2007)
Biomass (kg)	$ab = 0.0673 \times (\rho \times DBH^2 \times h)^{0.976}$ Where: *ab*: above-ground biomass, dry weight (kg) *DBH*: diameter at breast height (cm) *h*: total tree height (m) ρ: wood density (g/cm^3)	Chave *et al.* (2014)

Source: **Chave, J., Réjou-Méchain, M., Búrquez, A., Chidumayo, E., Colgan, M.S., Delitti, W.B.C., Duque, A.**, *et al.* 2014. Improved allometric models to estimate the aboveground biomass of tropical trees. *Global Change Biology*, 20(10): 3177–3190.; **Panama (Republic of).** *Resolution No. AG-0168-2007*, 2007.

As regards volume and biomass estimates, the equations used for these calculations can be found in Table 21.4.

According to Cochran (1977) and Queiroz (2012), the following equation can be used to estimate the sampling error of a variable *y* within an individual stratum:

$$e_y = \sqrt{\frac{s_h^2}{n_h}} \times \sqrt{1 - \frac{n_h}{N_h}}$$

where:

e_y = estimate of the standard error of the variable *y*

s_h = standard deviation of the variable *y* in the stratum

n_h = number of SUs in the stratum sample

N_h = total number of SUs in the stratum

Assuming that in the individual strata the population is infinite ($n < 0.05\ N$), the formula is simplified by ignoring the correction factor due to the finite population (Cochran, 1977; Quiroz, 2012), to obtain the sampling error of the variable *y* in the stratum, using the following formula:

$$e_y = \sqrt{\frac{s_h^2}{n_h}}$$

Hence, following Cochran (1977), as the sampling fractions n_h/N_h of all of the national inventory strata were found to be negligible, the formula considered to estimate the sampling error of the variable *y* in the population was as follows:

$$e_y = \sqrt{\sum \frac{W_h^2 \times s_h^2}{n_h}}$$

where:

e_y = estimate of the standard error of the variable y

s_h = standard deviation of the variable *y* in the stratum

n_h = number of SUs in the stratum sample

W_h = stratum weighting

21.6 RESULTS OF THE FIRST CYCLE: LAND AREA, BIOMASS AND VOLUME

Several countries use their national forest inventory to generate official area statistics for different land cover and land use categories, as field observations are more reliable than satellite image interpretations. However, because it is a sampling exercise, a considerable number of SUs is required to achieve an acceptable level of uncertainty. The analysis of variables in the NFCI database has not

yet been completed. Therefore, the results should be considered as preliminary data, as not all results represent data from the entire national territory with the desired level of confidence. Table 21.5 shows some of the results from the pilot phase of the inventory.

During the pilot phase of the first NFCI cycle, 648 tree species were recorded. Of these, 93.6 percent were identified at the family level, 92.2 percent at the genus level and 78.2 percent at the species level. The highest number of unknown individuals was recorded in Indigenous territories, where the collection of floristic material was not permitted, making identification to species level difficult. On the other hand, 17 endemic species and 62 threatened species were recorded according to MiAMBIENTE, of which two species were reported as critically endangered, eight endangered and 52 vulnerable species. Additionally, five species new to science were found (Melgarejo *et al.*, 2015).

It is important to mention that the LUC classification system established for Panama's NFCI1 was organized hierarchically into four different levels, the first levels being the least detailed in terms of the number of classes they contained. Land use class level 3 is also known as the NFCI special classes, as it defines the main forest categories. In total, ten categories or LUCs were established at this level; five of these are in the "forest" category and the remaining five are in the "non-forest" classes. Figure 21.8 presents the carbon averages (all sources) for LUC level 3 per climatic region, based on the 87 SUs surveyed with the NFCI1.

Table 21.6 provides details of the carbon averages for the above-ground part of living trees, for each of the 10 categories established in LUC level 3 and per climatic region. These carbon estimates were made for all sources, for the four LUC levels and per climatic region; the other variables (volume, biomass, etc.) were estimated in the same way.

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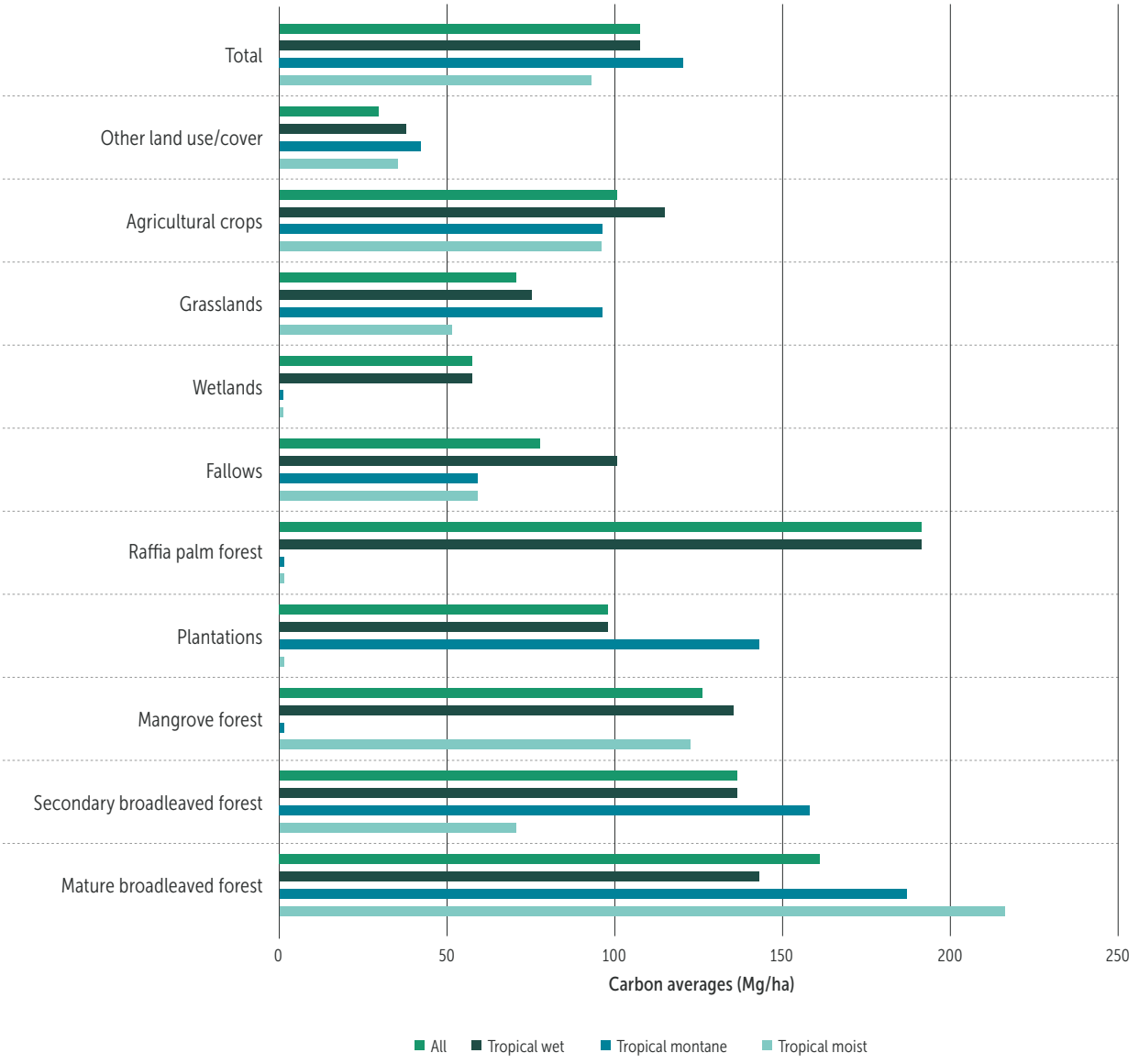
TABLE 21.5

Summary of results of the first 2013–2015 National Forest and Carbon Inventory (pilot phase)

Variable	National Forest and Carbon Inventory (NFCI) result (95% error)	Land cover and land use map 2012	Description
Forest area (ha)	4 295 321 (23.0%)	4 305 154	Includes primary, secondary, mangrove, palm and plantation forests
Non-forest area (ha)	3 068 087 (29.8%)	3 058 254	Includes grassland with trees
Total land area (ha)	7 363 408	7 363 408	
Volume (m^3/ha)	153.9 (26%)		Includes the average volume of all categories measured in the NFCI
Above-ground biomass (t/ha)	89.6 (26%)		Includes the average biomass of all categories measured in the NFCI

Source: **Castillo, M., Samaniego, R. & Kindgard, A.** 2015. *Mapa de cobertura y uso de la tierra 2012.* Panama City, Ministry of the Environment and UN-REDD programme.; **Melgarejo, C., Calderón, C., & Ruiz, M.d.C.** 2015. *Inventario Nacional Forestal y de Carbono de Panamá: Diseño de la Fase Piloto 2013-2015 y Propuesta para la Fase Final.* Panama City, Ministry of the Environment and FAO.

FIGURE 21.8
Carbon averages for land use class level 3 per climatic region



Source: **Calderón, A. & Calderón, J.** 2020. *Inventario Nacional Forestal y de Carbono de Panamá: Estimación de áreas y factores de emisión.* Panama City, Ministry of the Environment.

21.7 IMPLEMENTATION AND QUALITY CONTROL

Quality control of forest inventories is an activity that has received a great deal of attention in recent years, mainly in national forest inventories with complex designs and multiple objectives. Such inventories collect a great deal of information, which is based on consistent and accurate protocols.

In Panama's NFCI, the quality control approach is based on the random selection of a subset of SUs that are measured independently by two different field teams. The differences obtained by the two field crews are evaluated against quality standards for each variable and a set tolerance or threshold (attribute accuracy).

The overall objective of quality control is to ensure that the field data collection process is in alignment with the NFCI field manual and that the variables

TABLE 21.6

Carbon averages for the above-ground part of living trees (land use class level 3)

Land use/cover level 3	Climatic region					
	Tropical moist		Tropical montane		Tropical wet	
	Average (t/ha)	Sampling error (%)	Average (t/ha)	Sampling error (%)	Average (t/ha)	Sampling error (%)
Mature broadleaved forest	67.21	5.17	86.27	40.27	71.29	21.51
Secondary broadleaved forest	22.58	68.89	49.39	36.96	46.14	38.99
Mangrove forest	17.69	92.53	n/a	n/a	44.66	136.88
Plantations	n/a	n/a	76.42	n/a[1]	20.77	78.88
Raffia palm forest	n/a	n/a	n/a	n/a	65.24	n/a[1]
Fallow	10.63	175.91	8.10	55.32	18.56	50.49
Grasslands	2.97	84.40	8.16	47.95	6.54	57.01
Agricultural crops	0.40	84.15	16.08	115.99	13.35	77.79
Other use/cover	4.35	209.79	2.97	211.15	24.86	130.57
Total	**17.00**	**91.49**	**36.61**	**37.52**	**31.51**	**26.52**

Note: n/a: not applicable. [1] Cannot be calculated because the estimate comes from a single data point.
Source: **Calderón, A. & Calderón, J.** 2020. *Inventario Nacional Forestal y de Carbono de Panamá: Estimación de áreas y factores de emisión.* Panama City, Ministry of the Environment.

measured comply with certain tolerance thresholds. The quality of the data collected in the inventory was analysed and presented in a report, with the objective of achieving 100 percent data quality.

21.8 OTHER VARIABLES COLLECTED IN THE NATIONAL FOREST AND CARBON INVENTORY

The NFCI is multipurpose with a focus on the REDD+ objectives, with socioeconomic information on towns and villages that influence the SU; in addition to the name of the village and its number of inhabitants, the information collected includes details on the ethnic groups living there, available services and population dynamics, among others. The information on forest resources is mainly focused on calculating the content, such as carbon emissions and removals from deforestation and forest degradation, which is used to establish the baseline required for the NFMS. In addition to the variables needed to calculate biomass and volume, botanical samples of each tree species present in the SU were collected during the first NFCI to establish a reference collection, and data on topography, erosion, slope, stoniness, drainage and soil colour were recorded (Melgarejo *et al.*, 2015).

The information obtained from the survey of soil organic matter is noteworthy, due to the limited information available at national level on this subject. Organic carbon was measured in pits, approximately 1.50 m in length at up to 1 m deep, at three soil horizons: 0 cm to 30 cm, 30 cm to 60 cm, and more than 60 cm. At each horizon, samples were taken to determine fertility in the laboratory, soil colour, bulk density and carbon content in organic matter.

For UNFCCC purposes, carbon content in the first 30 cm of depth should be reported in country reports. However, to improve soil information in the country, information from all three horizons was collected and additional analyses were performed (Melgarejo *et al.*, 2015).

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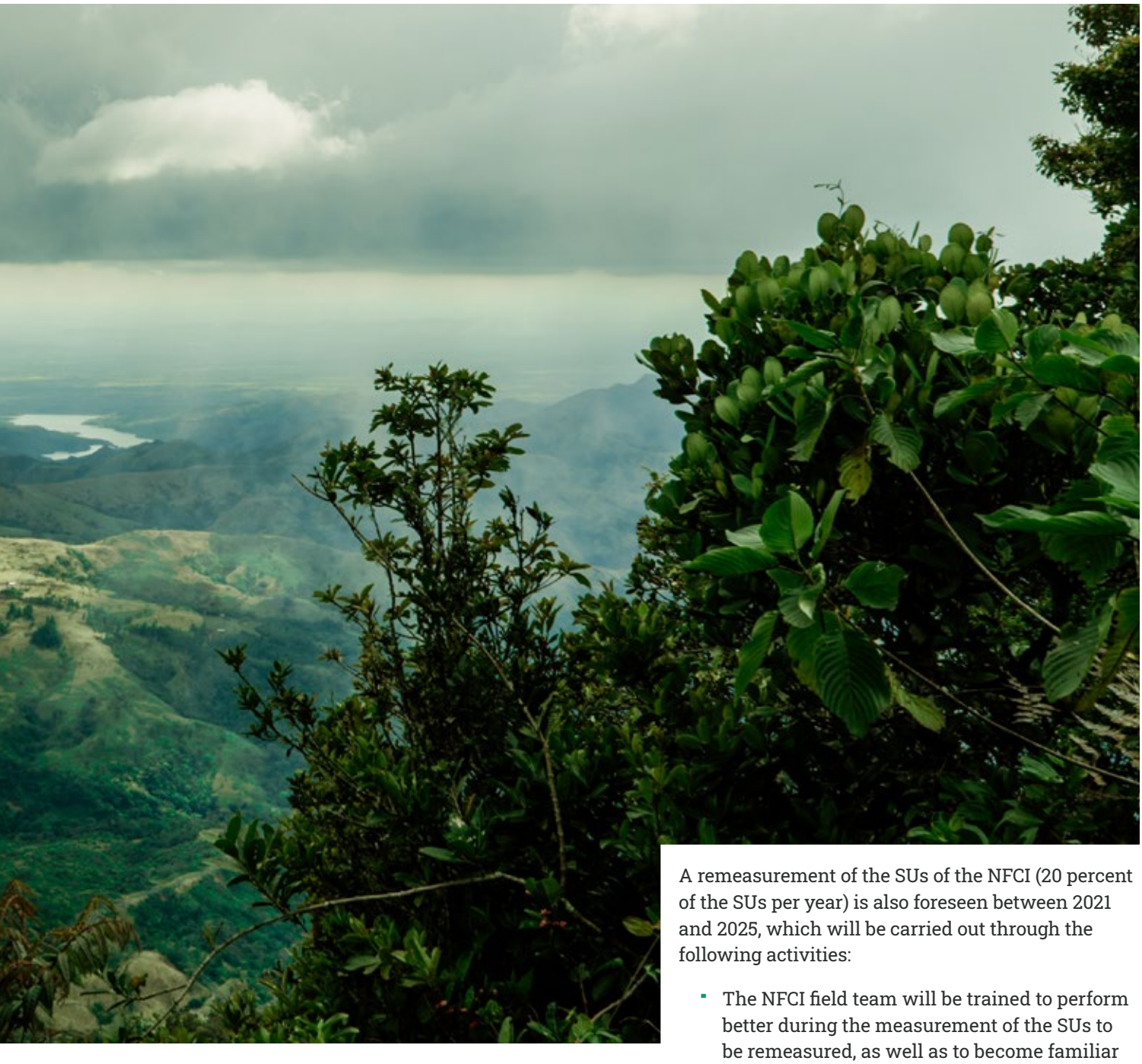
21.9 FUTURE PROSPECTS

Future prospects for the NFCI include improvements in the determination of activity data based on the recommendations and proposed refinements to the Forest Reference Emission Level (FRL/FREL) submitted to the UNFCCC. It includes improvements to the mapathon, the name given in Panama to the method of surveying geospatial data to determine land use changes (activity data) using the components of the Collect Earth architecture of the FAO Open Foris initiative (Bey *et al.*, 2015). This activity comprises the following tasks:

- Address errors in measurement or interpretation of land use assessment by adjusting quality assurance and quality control procedures with knowledge-sharing workshops.
- Make technical improvements to the application of Collect Earth imagery in order to improve historical data, by strengthening capacity to increase the number of interpreters per SU.
- Review the sampling design of the mapathon's grid of points, to assess the possibility of including the 32 LUCs and strengthening the reporting on CO_2 emissions of change classes, with an emphasis on forest land converted to non-forest land.



A remeasurement of the SUs of the NFCI (20 percent of the SUs per year) is also foreseen between 2021 and 2025, which will be carried out through the following activities:

- The NFCI field team will be trained to perform better during the measurement of the SUs to be remeasured, as well as to become familiar with the new SU inventory design; there will also be more technical staff trained in this area.
- Training on forest mosaic generation and analysis will be conducted in the SUs to count sample gains and losses; these will be targeted at two technicians per region.
- Training will continue on the use of the Silva Metricus Android tool for digital data collection in the SUs through the Android application package (APK), with the aim of increasing the number of technicians trained in the use of this tool.
- Permanent monitoring actions through periodic overflights of the SUs with drones are also foreseen.

- It is anticipated that more complete protocols on the interpretation of satellite images will be developed, to update the methodologies currently being used.
- Work will be conducted to improve the approach to forest degradation and management by broadening consultations on this component, as there were many conflicting views on the approach to this activity in the current FRL.
- A more efficient protocol for monitoring forest fires (based on remote sensing) is expected to be developed.

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NEXT CHAPTER

PERU

Chapter 22

PERU

NATIONAL FOREST AND WILDLIFE INVENTORY OF PERU

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22.1 HISTORICAL OVERVIEW OF NATIONAL FOREST INVENTORIES IN PERU

The implementation of a national forest inventory has been of interest to Peru since the beginning of forestry sciences in the country. In 1963, the School of Forestry Sciences of the Universidad Nacional Agraria La Molina (UNALM) was established with the support of the Food and Agriculture Organization of the United Nations (FAO), which in turn supported the General Directorate of Forestry and Hunting (Dirección General Forestal y de Caza in Spanish). Knowledge of the country's forestry potential was considered essential for the development of its forestry policy. In this context, the Forest Management Department (Departamento de Manejo Forestal in Spanish) of UNALM, with the support of the FAO/UNDP Project 116 (PER20) for Forestry Education and Research in Peru, led an initial effort that included the following activities:

- Development of a catalogue of forest assessment work up to 1972, published jointly by the DMF and the National Office for the Assessment of Natural Resources (Oficina Nacional de Evaluación de Recursos Naturales);
- Publication of the *Forest Map of Peru* by the DMF (Malleux, 1975), at a scale of 1:1 000 000, developed with aerial-photographic mosaics and panchromatic aerial photographs of different scales, using physiographic-floristic criteria and establishing classes of forest resource potential;
- Implementation of the National Forest Inventory (NFI), whose field phase was conducted between 1981 and 1982.

The implementation of this National Forest Inventory required the establishment of a national commission made up of government actors from central and regional levels. In its conception, the NFI should promote national and regional forest inventories; provide information for the forest development plan; normalize and standardize methods and develop inventory methodologies; and provide reliable information for state and private institutions.

The NFI proposed to divide the country into squares measuring 120 kilometres (km) on each side, subdivided into quadrangular sub-blocks of 30 km on each side, and sampling areas of 5 km on each side, within which the plots would be established ("systematic strips or plots, as appropriate" according to Malleux, 1975, cited by Barrena *et al.*, 2011), with a remeasurement every 10 years. The statistical probability of the error would be 20 percent to 95 percent.

The plans to conduct the NFI only came to fruition in 1979, establishing a priority area for the assessment of natural forests in the Central Forest and, for the assessment of forest plantations, the Andean part of the departments of Cusco and Huánuco. After a planning and design phase for the inventory, which took place in 1980, a field phase

was conducted by the DMF between 1981 and 1982, which unfortunately remained incomplete due to a lack of financial resources.

A total of 1 714 914 hectares (ha) of land in the Selva Central was assessed, using aerial photographs for the generation of maps, with some areas that would be mostly protected due to their steep physiography. It was also determined that deforestation was significant, representing more than 18 percent of the assessed land area. A total of 199 sample plots were surveyed, and it was found that the forest had good potential, but lacked so-called "valuable" species (from the point of view of their marketing potential for the timber industry).

Regarding the forest plantation assessment, results in the department of Cusco indicated that the plantations spanning more than 1 ha and located more than 2 800 metres above sea level (masl) represented a total of 11 670 ha (considerably less than the official statistics). Of this land area, 57 percent corresponded to plantations smaller than 10 ha, and only 19 percent to areas larger than 30 ha.

In 1995, the General Directorate of Forestry (formerly the General Directorate of Forestry and Hunting) of the National Institute of Natural Resources (Instituto Nacional de Recursos Naturales – INRENA, according to its acronym in Spanish) published the *Forest Map of Peru*, which provided updated information on forest cover, although the classification criteria differed from those of the 1975 map. The new map was developed by applying an eco-floristic approach, based on 1990 Landsat images at a scale of 1:250 000 (according to INRENA, 1995, cited by Barrena *et al.*, 2011).

This was followed by another forest map produced by INRENA in 2000, based on the visual interpretation of Landsat images, with classification criteria different from those of the 1975 and 1995 maps. Although this map was not published, it was widely used in digital format.

In 2011, within a context of global concern for climate change and sustainable development, as well as the free trade agreement between Peru and the United States of America, it was considered essential to strengthen capacities to acquire, process, manage and analyse forest resource information. The Government of Peru established an agreement with FAO for the implementation of the project "National forest inventory and sustainable forest management in Peru in the face of climate change" (GCP/GLO/194/MUL). The project was implemented by the Ministry of Agriculture and the Ministry of the Environment, with the consultative participation of a Technical Support Group made up of officials from both ministries, as well as experts from the United States Forest Service and members of Peruvian academia.

Within the framework of this project, the methodological framework was developed in 2012, the sampling design was established and field operations began in 2013. Data collection and information reporting are processes that continue to be conducted by the National Forest and Wildlife Service, through the Inventory and Valuation Directorate.

The National Forest and Wildlife Inventory (NFWI) of Peru is thus the means to collect data and generate information in a continuous, updated and reliable manner, in order to monitor the status and diversity of forests in Peru, including natural forests, forest plantations and secondary forests; the inventory involves collecting and processing data on biomass, biodiversity, carbon stock, deforestation, greenhouse gas emissions, wildlife status and socioeconomic information on the populations of rural settlements. The NFWI has been conceived as a continuous process, in which measurements will be taken permanently over the years to analyse changes in the country's forest ecosystems.

Table 22.1 presents a historical overview of national forest inventories in Peru.

TABLE 22.1

Historical overview of national forest inventories in Peru

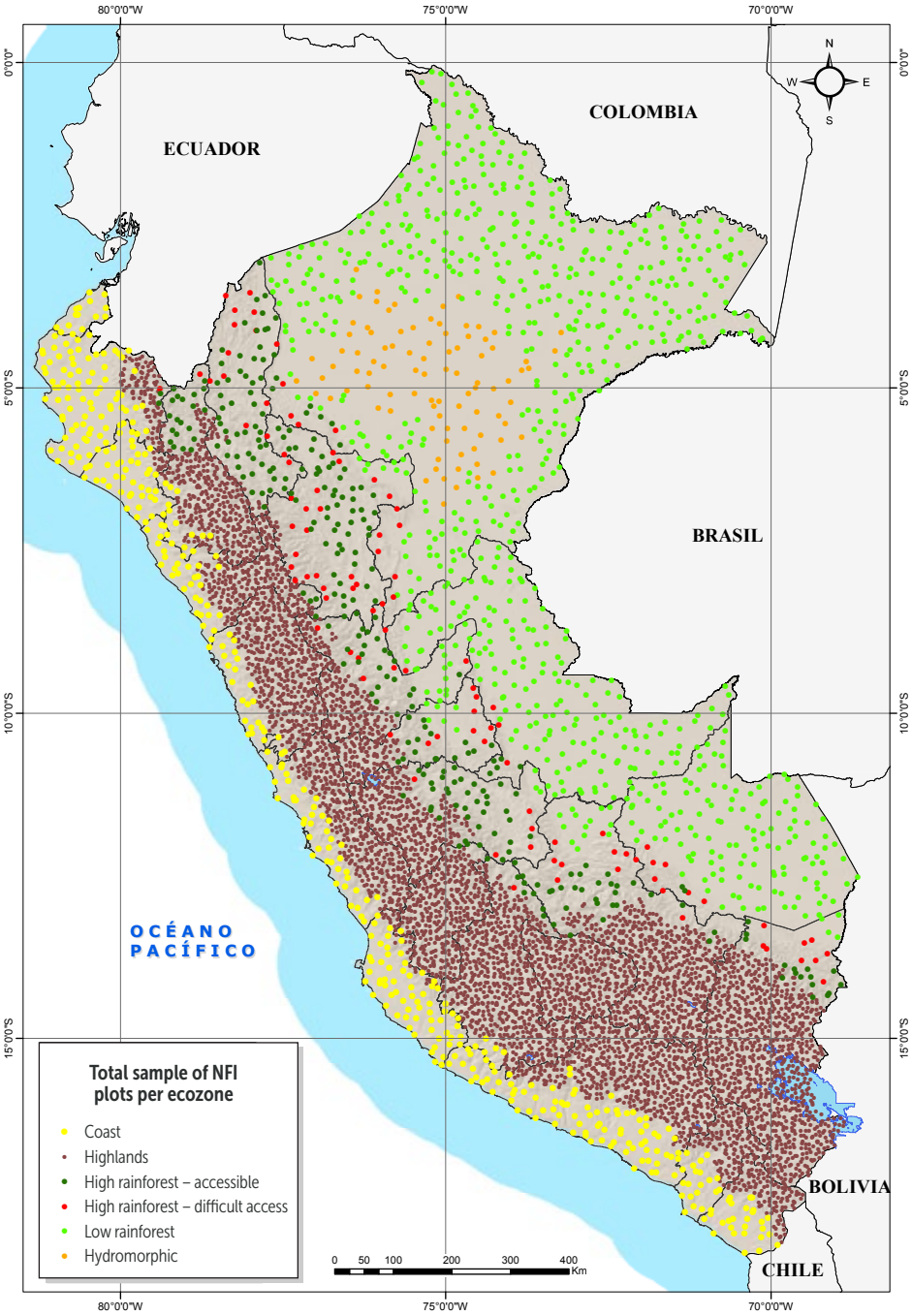
Inventory cycle	Implementation period	Scale	Sampling design	Number of sampling units
NFI	1975–1980	National	Multistage cluster sampling design. National grid with 120 km × 120 km blocks, and 30 km × 30 km and 5 km × 5 km sub-blocks (Malleux, 1975).	Unknown
NFWI	2013–2018	National	Six subpopulations (ecozones) with different sampling intensities determined by different grid sizes. Each grid cell contains a randomly located sampling unit (systematic non-aligned). The sampling design is two-stage cluster sampling with unequal cluster sizes (Cochran, 1977).	7 293 (of which 1 797 correspond to forests)

Source: **Malleux, J.** 1975. *Mapa Forestal del Perú (Memoria Explicativa).* Lima, Departamento de Manejo Forestal, Universidad Nacional Agraria La Molina.; **MINAGRI (Ministry of Agriculture and Irrigation of Peru) & MINAM (Ministry of the Environment of Peru).** 2016. *Marco metodológico del Inventario Nacional Forestal y de Fauna Silvestre.* Lima.

Figure 22.1 shows the distribution of all sampling units for the six ecozones over the entire national territory in forest and non-forest areas. The different density of sampling units for each ecozone is the result of the different grid sizes.

FIGURE 22.1

Distribution of the sampling units of the National Forest and Wildlife Inventory of Peru according to subpopulations or ecozones



The boundaries shown and the names and designations used on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any countries, territories, cities, areas, authorities, or delimitation of their frontiers or boundaries. Dotted lines on maps represent approximate boundaries for which there may not yet be full agreement.

Source: **SERFOR.** 2019b. *Manual de Campo del Inventario Nacional Forestal y de Fauna Silvestre del Perú. Instructivo para la colecta de datos.* (Unpublished). Lima.

TABLE 22.2

Summary of definitions used to implement the National Forest and Wildlife Inventory

Term	Definition	Variables and thresholds
Forest	A predominantly tree-dominated ecosystem extending over 0.5 ha, with a minimum width of 20 m and a minimum canopy cover of 10%, with trees at least 2 m in height in the coastal and highland regions and 5 m in the Amazon rainforest, or trees capable of reaching those heights in the aforementioned regions (MINAGRI and MINAM, 2016).	Minimum area: 0.5 ha Minimum width: 20 m Canopy cover: 10% or greater Potential tree height: from 2 m in the coastal and highland regions; from 5 m in the Amazon region.
Other wooded land	While this class has not been explicitly defined for the National Forest and Wildlife Inventory, it includes areas that are not classified as forest, as their canopy cover does not reach 10%, regardless of whether tree height reaches 5 m in the Amazon and 2 m in the coastal and highland regions. It also includes areas of shrubs and bushes with no trees. Usually, this class includes the shrubs that are distributed in a large area of the country, especially the shrubs of arid zones located in the highlands ecozone, western Andean region, with typical species such as the huanarpo, huancoy, mito, maguey, lloque, huaranhuay, and sclerophyllous shrublands of the genera *Weinmannia, Clusia, Persea,* etc. (SERFOR, 2019b).	Minimum area: not established Canopy cover: less than 10%, with potential tree height greater than 5 m in the Amazon or 2 m in the coast and highlands; or greater than 10% and with potential tree height less than 5 m in Amazonia and 2 m in the coast and highlands. Areas of shrubs and bushes with no trees.
Other land	Includes all land that is not considered as "forest" or "other wooded land," including land whose current land cover or land use may be one of the following: hydrophytic herbland, hydrophytic savannah, coastal wetland, Andean herbland, meadow, puya stands, Andean grasslands, paramo, desert, rocky areas, glaciers and bodies of water in general, agriculture, livestock farming, agroforestry, fallow land, infrastructure and villages (SERFOR, 2019b).	
Volume	Timber volume: corresponds to the volume of standing trees in cubic metres (m^3), calculated based on the diameter at breast height (DBH) (including bark) and the height of the stem, to which the form factor of 0.65 is applied for the Amazon (Low Rainforest, Accessible High Rainforest, High Rainforest of Difficult Access, and Hydromorphic ecozones). For the Coast and Highlands ecozones, the form factor is 0.70 (SERFOR, 2019a).	Base measurement diameter: from 5 cm for the Coast and Highlands ecozones; from 10 cm for the other ecozones The stem height corresponds to the height of the stem from its base to the branching point. Branches are included in the case of shrubs and trees branching at less than 1.30 m in height. In the case of branches and shrubs, the length of the woody part of the element is estimated Includes bark
Living biomass	Above-ground biomass: dry biomass in kilograms of living trees, palms and lianas with DBH of 5 cm or more.	Above-ground biomass: minimum diameter (DBH, at 1.30 m from the ground): 5 cm for Coast and Highland ecozones; 10 cm for the rest of the country
	Below-ground biomass: estimated using the Mokany *et al.* (2016) equation from above-ground biomass values.	Below-ground biomass: not measured

Source: **MINAGRI & MINAM.** 2016. *Marco metodológico del Inventario Nacional Forestal y de Fauna Silvestre.* Lima.; **SERFOR (National Forest and Wildlife Service).** 2019a. *Informe del Inventario Nacional Forestal y de Fauna Silvestre del Perú. Panel 1.* Lima.;

22.2 TERMS AND DEFINITIONS RELEVANT TO THE IMPLEMENTATION OF THE NATIONAL FOREST AND WILDLIFE INVENTORY

The definitions used for volume, living biomass and areas of interest for the NFWI of Peru are presented below. A summary of these variables is presented in Table 22.2.

- **Volume:** Referred to as the timber volume, it is the standing roundwood calculated for living trees, based on the diameter measured at breast height and stem height, plus a form factor according to subpopulation.
- **Living biomass:** Living biomass comprises the above-ground dry biomass of living trees, palms and lianas, considering the following measurement thresholds: minimum diameter (diameter at breast height [DBH]) of 5 cm for the Coast and Highlands ecozones, and 10 cm for the rest of the country. It also includes root biomass, which is calculated using the equation developed by Mokany *et al.* (2016), based on above-ground biomass values.
- **Areas of interest in the NFWI:** According to the methodological framework, "the population of interest of the NFWI is Peru's entire mainland, where attributes and changes in relation to forests are estimated" (MINAGRI and MINAM, 2016). The different types of forests, plant formations and other land uses are arranged in current land use classes (LUC), which were defined based on the *National Land Cover Map* prepared by the Ministry of the Environment of Peru (2015).

22.3 SAMPLING DESIGN

The definition of the population of interest, the configuration of the sampling units, and the sampling design of the NFWI were established based on the following considerations.

The NFWI should respond to the information needs in the following thematic areas:

- *Assessment and evaluation of forest resources.*
- *Area, deforestation and degradation of forests.*
- *Forest carbon removals and emissions.*
- *Biological diversity of forest ecosystems.*
- *Socioeconomic and forest governance aspects (MINAGRI and MINAM, 2016, p. 10).*

In addition to the above, the NFWI:

- *Should consider the country's accessibility constraints.*
- *Should respond to a permanent monitoring of forests.*
- *Should facilitate the mobilisation of economic, human and logistical resources (MINAGRI and MINAM, 2016, p. 15).*

Given the ecosystem complexity and different accessibility conditions, six subpopulations of interest (ecozones) were determined for the NFWI, with the objective of optimizing the sampling design in each of them. A different grid size was created for each ecozone, with each grid cell containing a randomly located, non-aligned sampling unit (SU) (MINAGRI *et al.*, 2016).

The six ecozones, shown in Figure 22.2, were defined based on five criteria: physiographic, physiognomic, floristic, carbon storage capacity and accessibility criteria. Their main characteristics are as follows:

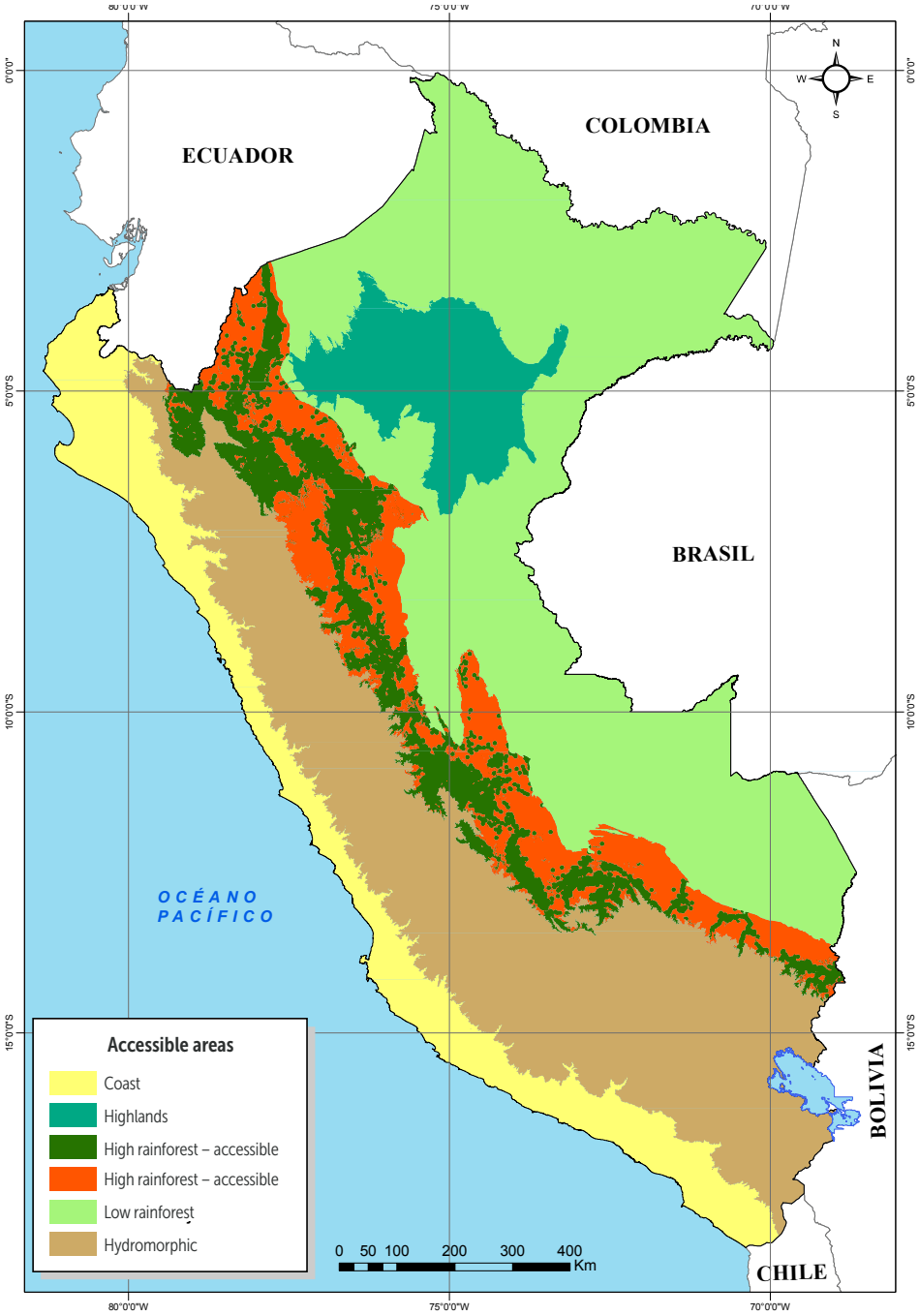
- *Coast, primarily desert area between 0 and 2 000 masl, with the presence of dry forests distributed mainly in the north of the country.*
- *Highlands, Andean zone. From 2 000 masl (in the Coast ecozone), reaching up to 6 000 masl and descending in the eastern zone to 3 800 masl. The predominant land cover is high Andean grassland and paramos. The forests are high and meso-Andean low-growing, relict-type homogeneous forests with strong levels of intervention, complemented by the dry forests of the inter-Andean valleys.*
- *Accessible high rainforest, between 500 and 3 800 masl, with no more than 20 km of human infrastructure or deforested areas.*
- *High rainforest of difficult access, between 500 and 3 800 masl, with more than 20 km of human infrastructure or deforested areas.*
- *Low rainforest, in the Peruvian Amazon between 100 and 500 masl.*
- *Hydromorphic forest, determined by the Pastaza alluvial fan, flooded forest areas predominate, more homogeneous and due to their flooding conditions, a greater storage of soil carbon is expected (MINAGRI and MINAM, 2016, pp. 15–16).*

In each subpopulation, the sample size is different, due to: i) accuracy targets; ii) variability of key attributes; iii) plot configuration; iv) forest area allocated to meet accuracy targets; v) accessibility; and vi) field survey costs.

Once the sample size was determined (7 293 SUs distributed in a systematic non-aligned design), the next step was the SUs coverage analysis. A preliminary visualisation of the coverage of each SU was obtained from Google Earth images.

FIGURE 22.2

Subpopulations or ecozones of the National Forest and Wildlife Inventory of Peru

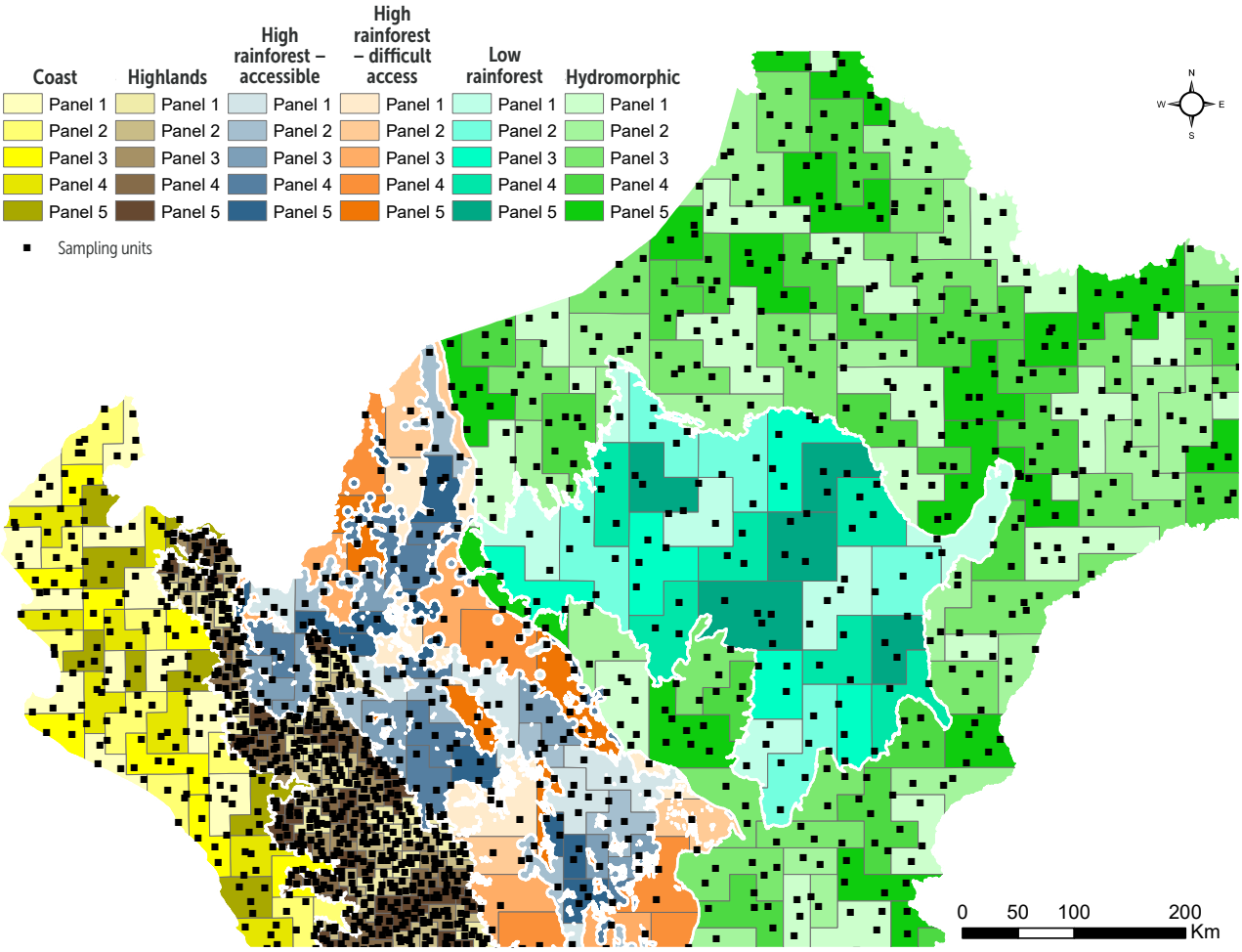


The boundaries shown and the names and designations used on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any countries, territories, cities, areas, authorities, or delimitation of their frontiers or boundaries. Dotted lines on maps represent approximate boundaries for which there may not yet be full agreement.

Source: **MINAGRI & MINAM.** 2016. *Marco metodológico del Inventario Nacional Forestal y de Fauna Silvestre.* Lima.

FIGURE 22.3

Groups and panels of sampling units and clusters of the National Forest and Wildlife Inventory of Peru



The boundaries shown and the names and designations used on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any countries, territories, cities, areas, authorities, or delimitation of their frontiers or boundaries. Dotted lines on maps represent approximate boundaries for which there may not yet be full agreement.

Source: **MINAGRI & MINAM.** 2016. *Marco metodológico del Inventario Nacional Forestal y de Fauna Silvestre.* Lima.

The SUs that showed forest in at least one record unit (RU) were selected for field evaluation (where the biophysical observations should be made), while those that did not meet this condition were excluded from field visits.

The sampling units with land cover that was not visible due to clouds or shadows in the image were also selected for field visits. Thus, the sample to be assessed consisted of a total of 1 797 SUs, which were grouped into clusters. These clusters were then regrouped into five panels (where each panel corresponds to 20 percent of the total field sample) with a balanced spatial distribution, so that the SUs of each cluster can be remeasured every five years.

This design behaves as a two-stage cluster sampling, where the clusters are the primary units and the SUs are the secondary units.

Figure 22.3 shows the configuration of the clusters that correspond to each of the small polygons into which the territory has been divided within the ecozones, each containing more than one SU (black dots) with or without forest. The clusters are grouped into panels, thus it follows that all the SUs of a specific cluster correspond to only one panel.

Table 22.3 presents the classification of the sampling units of Peru's NFWI, where three categories are considered:

- Sampling units classified as "forest" refer to the SUs that have at least one of their subunits with forest, while the rest may be "non-forest"; these SUs will require field assessment.
- Sampling units classified as "undetermined" refer to the SUs where there is uncertainty over the presence of forest in any of their subunits because the satellite images used in the planning phase were unclear. A field visit or the use of other remote sensing tools (for instance, drones) will be required to confirm coverage.
- Sampling units classified as "non-forest" have no forest in any of their subunits; therefore, field assessment will not be carried out in these areas. It is important to note that the number of forest SUs (currently 1 797) is variable due to changes in land cover, which are periodically verified by satellite imagery for data collection planning purposes.

22.4 SAMPLING UNIT DESIGN

According to the field manual (SERFOR, 2019b), the SUs of the NFWI have two different configurations, which are characterized by an L-shaped design composed of a cluster of plots, with nested design and different measurements according to the variable being assessed.

22.4.1. SAMPLING UNIT FOR THE COAST, HIGHLANDS, ACCESSIBLE HIGH RAINFOREST, HIGH RAINFOREST OF DIFFICULT ACCESS AND HYDROMORPHIC ECOZONES

As shown in Figure 22.4, the SU consists of an L-shaped cluster, with an axis length of 276.2 metres (m) oriented towards the north and a similar axis oriented towards the east. The total area of the SU is 5 000 square metres (m²) (equivalent to 0.5 ha), divided into ten circular plots with a radius of 12.62 m, equivalent to 500 m² (0.05 ha). Five plots are located on each axis, 30 m apart.

For the Coast and Highlands ecozones, living trees with DBH greater than or equal to 10 cm are measured throughout the entire SU. In plots 1, 3, 5, 7 and 9, the poles (trees with DBH between 5 cm and 9.99 cm) are measured. Plots 3, 5 and 7 are smaller subplots, where natural regeneration is measured in terms of saplings and seedlings.

TABLE 22.3

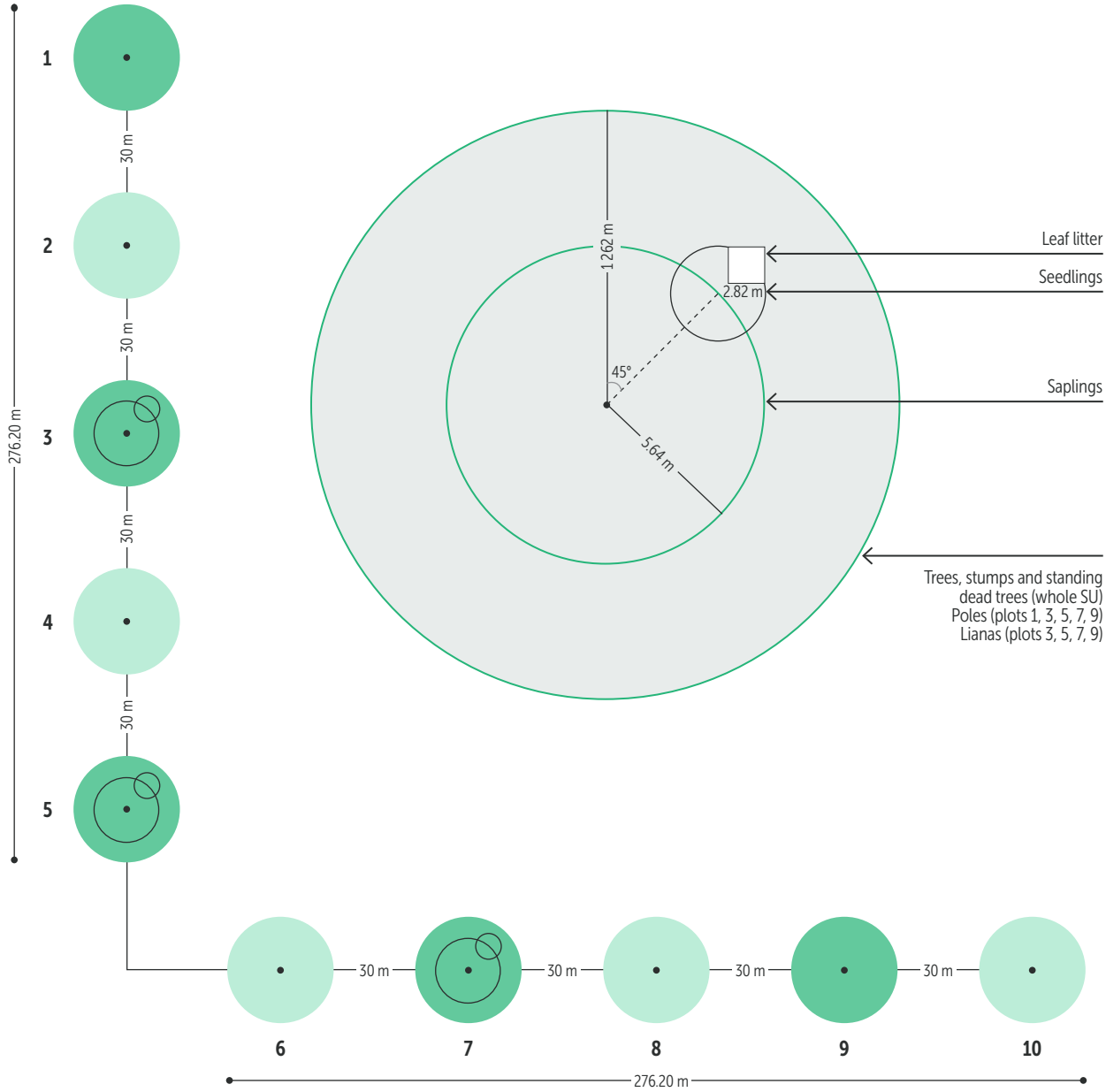
Sampling design characteristics

Ecozones	Total land area (1 000 ha)	Sampling unit categories per land cover type			Total sampling units
		Forest	Undetermined	Non-forest	
Coast	15 130	102	7	351	460
Highlands	35 518	465	29	5 051	5 545
Accessible High Rainforest	11 161	242	5	41	288
High Rainforest of Difficult Access	11 413	101	0	0	101
Low Rainforest	47 473	799	3	6	808
Hydromorphic	8 731	88	0	3	91
Total	**129 427**	**1 797**	**44**	**5 452**	**7 293**

Source: Prepared by the authors.

FIGURE 22.4

Sampling unit configuration for the Coast, Highlands, Accessible High Rainforest, High Rainforest of Difficult Access, and Hydromorphic ecozones

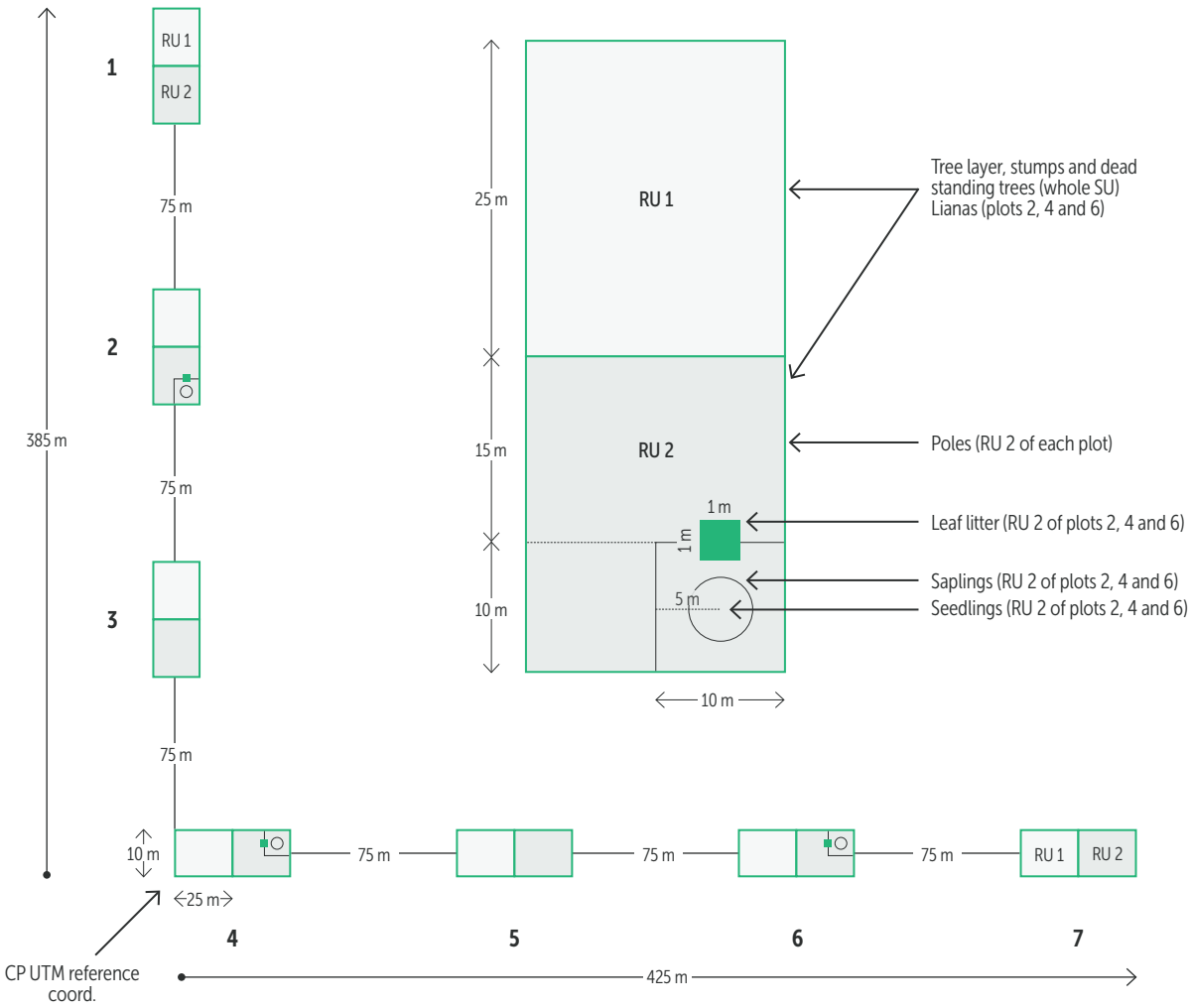


Note: SU: sampling unit.
Source: **SERFOR.** 2019b. *Manual de Campo del Inventario Nacional Forestal y de Fauna Silvestre del Perú. Instructivo para la colecta de datos.* (Unpublished). Lima.

The saplings (growing plants with a diameter of less than 5 cm, measured at a height of 30 cm above the ground, and with a total height between 1 m and 3 m) are measured in subplots with a radius of 5.64 m, equivalent to 100 m² (0.01 ha). Seedlings (plants between 0.3 m and 1 m in height) are measured in subplots with a radius of 2.8 m, equivalent to 25 m² (0.0025 ha).

For the Accessible High Rainforest, High Rainforest of Difficult Access and Hydromorphic ecozones, living trees with DBH greater than or equal to 30 cm are measured throughout the entire SU. In plots 1, 3, 5, 7 and 9 the poles are measured (trees from 10 cm to 29.9 cm DBH). Natural regeneration is also measured in nested subplots within plots 3, 5 and 7, in terms of saplings (plants with DBH less than 10 cm and height greater than 3 m) and seedlings (young plants with heights between 1 m and 2.99 m).

FIGURE 22.5
Sampling unit configuration for Low Rainforest ecozone



Note: CP: central point; m: metres; RU: record unit; SU: sampling unit; UTM: Universal Transverse Mercator.
Source: **SERFOR.** 2019b. *Manual de Campo del Inventario Nacional Forestal y de Fauna Silvestre del Perú. Instructivo para la colecta de datos.* (Unpublished). Lima.

22.4.2. SAMPLING UNIT FOR THE LOW RAINFOREST ECOZONE

As shown in Figure 22.5, the sampling unit used for low rainforest is a cluster of plots arranged in an "L" shape, with one axis oriented towards the north (length: 385 m) and another axis oriented towards the east (length: 425 m). The total area of the SU is 7 000 m² (0.7 ha), divided into seven rectangular plots of 50 m in length and 20 m wide, equivalent to 0.1 ha each. The distance between the plots is 75 m.

In the seven plots, trees larger than 30 cm DBH are measured. Each plot consists of two RUs measuring 25 m in length and 20 m in width, equivalent to 500 m² (0.05 ha). In the even-numbered RUs, the poles are also measured (growing trees between 10 cm and 29.9 cm DBH).

Natural regeneration is measured in nested subplots in RU 2 in plots 2, 4 and 6 (saplings which have DBH less than 10 cm and height greater than 3 m, and seedlings that are between 1 m and 2.99 m in height).

The population strata per ecozone are presented in Table 22.4. In all cases, the term "individual" should be understood as any plant specimen that can be assessed; that is, it has the minimum size specified for the stratum and plot (whether tree, shrub, cactus, liana or even fern). Such data are of interest from the point of view of biomass and carbon stock records.

TABLE 22.4
Population strata per ecozone

Ecozone	Stratum	Definition
Coast and Highlands	Trees	Individuals with diameter at breast height (DBH) greater than or equal to 10 cm
	Pole	Individuals with DBH greater than or equal to 5 cm, but smaller than 10 cm
	Sapling	Individuals with diameter smaller than 5 cm (at 30 cm from the ground) and height between 1 m and 2 m
	Seedling	Young plants between 0.30 m and 1 m in height
High Rainforest (Accessible and of Difficult Access), Low Rainforest and Hydromorphic	Trees	Individuals with DBH greater than or equal to 30 cm
	Pole	Individuals with DBH greater than or equal to 10 cm, but smaller than 30 cm
	Sapling	Individuals with DBH smaller than 10 cm and higher than 3 m
	Seedling	Young plants between 1 m and 3 m in height

Source: Prepared by the authors.

22.5 TIMBER VOLUME, BIOMASS AND FOREST AREA CALCULATIONS

The timber volume is calculated for living standing trees, which are measured considering the particularities of their structure. The calculation of the timber volume differs according to the ecozone, as described in Table 22.5.

Above-ground biomass is all living vegetation that is found above the ground, including stems, branches, seeds, flowers and leaves. For ease of measurement, above-ground biomass is separated into tree and non-tree above-ground biomass (since trees, shrubs, palms and any vegetation that reaches the minimum size for the ecozone are measured). On the other hand, below-ground biomass is considered to be the biomass that makes up the living roots, which is estimated based on the above-ground biomass.

Leaf litter is defined as all above-ground necromass (leaves, flowers, bark, branches, stems and fruit shells) that is not included in dead wood (standing or lying), above or within the mineral or organic soil, including detritus and humus. In addition, a fraction of necromass is lying dead wood, which is estimated based on the measurement of fallen stems and branches on the ground with a diameter greater than 10 cm.

The NFWI enables the forest area to be estimated for each ecozone; likewise, land use changes can be monitored over time based on the LUC variable. The forest area is thus calculated based on the LUC data, which are obtained in two ways: i) visits to the SUs by the field crews; and ii) remote sensing for the SUs classified as non-forest (which are not visited) and for the SUs classified as forest yet inaccessible for different reasons (geographical risks, prohibition of access by social actors, danger due to illegal activities, land inhabited by Indigenous populations in voluntary isolation, among others). In this sense, the estimate of the forest area of each ecozone can be obtained from the sampling of the NFWI SUs, as well as the estimated sampling error (Table 22.5).

TABLE 22.5

Equations used for volume, biomass and forest area calculations

Variable	Equation	Reference
Timber volume (m^3)	$V = \pi/4 \times DBH^2 \times Hc \times ff$ Where: V: timber volume (m^3) DBH: diameter at breast height (m) Hc: stem length (m) ff: for the Coast and Highland ecozones a 0.70 form factor was considered; for the other ecozones a value of 0.65 was applied π: pi (3.1416)	SERFOR (2019a)
Above-ground biomass (kg)	Coast: $0.112 \times (\rho \times DBH^2 \times Ht)^{0.916}$ Highland: $0.112 \times (\rho \times DBH^2 \times Ht)^{0.916}$ High Rainforest: $\rho \times Exp\ (-1.239 + 1.980 \times Ln\ (DBH) + 0.207 \times Ln\ (DBH)^2 - 0.0281 \times Ln\ (DBH)^3)$ Low Rainforest: $\rho \times Exp\ (-1.499 + 2.148 \times Ln\ (DBH) + 0.207 \times Ln\ (DBH)^2 - 0.0281 \times Ln\ (DBH)^3)$ Hydromorphic: $\rho \times Exp\ (-1.239 + 1.980 \times Ln\ (DBH) + 0.207 \times Ln\ (DBH)^2 - 0.0281 \times Ln\ (DBH)^3)$ Where: Ht: Total height (m) DBH: diameter at breast height (m) ρ: wood density (g/cm^3)	Chave *et al.* (2005)
Root biomass (kg)	$BGB = 0.489 \times AGB^{0.89}$ Where: BGB: below-ground biomass AGB: above-ground biomass	Mokany *et al.* (2016)
Leaf litter necromass (kg)	$Bh = Tft \times \left(\frac{Dws}{Fws}\right)$ Where: Bh: leaf litter necromass (kg) Dws: dry weight of sample collected (kg) Fws: fresh weight of sample collected (kg) Tfw: total fresh weight per plot (kg)	SERFOR (2019a)
Lying dead wood necromass (kg)	$Vol = (\pi^2 \sum (d_n)^2) / (8 \times L)$ Where: Vol: volume d_n: lying tree diameter (cm) L: transect length (m) π: pi (3.1416) $Necromass$ = volume × degree of decay	De Vries (1986)

TABLE 22.5 (CONTINUED)

Variable	Equation	Reference
Forest area (ha)	$S_b = N/n \times \sum S_{clm} \times \bar{x}_{pbpcm}$ Where: S_b: forest area for the ecozone N: total number of clusters in the ecozone n: number of clusters sampled S_{clm}: land area of each sampled cluster $\bar{x}_{pbpcm}$: average of the proportion of forest in the sampling units for each sampled cluster	Cochran (1977)

Source: **Chave, J., Andalo, C., Brown, S., Cairns, M.A., Chambers, J.Q., Eamus, D., Fölster, H.**, *et al*. 2005. Tree allometry and improved estimation of carbon stocks and balance in tropical forests, *Oecologia*, 145: 87–99.; **De Vries, P.G.** 1986. *Sampling Theory for Forest Inventory*. Berlin, Springer-Verlag.; **Mokany, K., Ferrier, S., Connolly, S. R., Dunstan, P. K., Fulton, E. A., Harfoot, M. B., Harwood, T. D.**, *et al.* 2016. Integrating modelling of biodiversity composition and ecosystem function. *Oikos*, 125(1): 10–19.; **SERFOR.** 2019a. *Informe del Inventario Nacional Forestal y de Fauna Silvestre del Perú. Panel 1*. Lima.;

22.6 RESULTS OF THE NATIONAL FOREST AND WILDLIFE INVENTORY

The results of timber volume, biomass and forest area presented in Tables 22.6, 22.7 and 22.8 correspond to NFWI Panel 1.

The volume per hectare for the six ecozones of NFWI Panel 1 has been estimated considering living tree and shrub measurements made in the pole and tree strata, as presented in Table 22.6. The calculation included tree and shrub stems with branches only (palm volume was not included).

The highest timber volumes have been obtained in Amazonia. The highest value is in the Low Rainforest ecozone (7 106.44 million m³). The gradient decreases as the altitude rises, towards the ecozones of Accessible High Rainforest and High Rainforest of Difficult Access (with values of 674.94 million m³ and 260.07 million m³, respectively).

The timber volume for the Coast and Highlands ecozones considers the main stems of trees and shrubs, in addition to the branches that have reached the minimum diameter specified for the ecozone (5 cm for both ecozones). These conditions influence the increase in volume, especially in the Coast ecozone, with a value of 65.96 million m³, and 13.71 million m³ for the Highlands ecozone.

With regard to the amount of living biomass and necromass, the Low Rainforest ecozone stores on average the largest amount, with 13 016.41 million tonnes, while the Hydromorphic, High Rainforest of Difficult Access and Accessible High Rainforest ecozones have values of 1 614.24 million tonnes, 339.18 million tonnes and 1 022.58 million tonnes, respectively.

At the level of the Highlands and Coast ecozones, the biomass and stored necromass decrease considerably compared to the Amazon, reaching values of 48.62 million tonnes and 69.95 million tonnes, respectively (see Table 22.7).

With regard to forest area, Table 22.8 presents the estimated land area for each ecozone (in thousands of hectares). It can be seen that the Low Rainforest and Hydromorphic ecozones have the lowest sampling error because these land areas are almost entirely forest (compared to total land area); in addition, the level of progress of the field assessment is higher. The Coast and Highlands ecozones have a higher sampling error, due to the smaller proportion of forest area; in addition, the level of progress in field assessments is lower than in Low Rainforest and Hydromorphic ecozones. High Rainforest of Difficult Access has the highest sampling error given that the field assessment is limited due to difficulties in accessing these areas.

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TABLE 22.6

Results of the National Forest and Wildlife Inventory of Peru, Panel 1: timber volume

Ecozone	Timber volume of the pole stratum		Timber volume of the tree stratum		Total timber volume	
	Volume (million m^3) (a)	Sampling error (%)	Volume (million m^3) (b)	Sampling error (%)	Volume (million m^3) (a + b)	Sampling error (%)
Coast	2.90	29.16	63.06	38.82	65.96	35.42
Highlands	2.03	23.05	11.69	23.89	13.71	23.23
Accessible High Rainforest	218.22	23.45	456.72	25.54	674.94	22.51
High Rainforest of Difficult Access	68.46	68.28	191.62	79.99	260.07	76.42
Low Rainforest	1 992.42	12.59	5 114.02	11.81	7 106.44	11.79
Hydromorphic	326.61	22.61	471.57	21.63	798.18	14.89

Note: sampling error at 95% confidence level.
Source: Prepared by the authors.

TABLE 22.7

Results of the National Forest and Wildlife Inventory of Peru, Panel 1: biomass and necromass per carbon pool

Ecozone	Biomass (million tonnes)		Necromass (million tonnes)		Total (sampling error in %)
	Above-ground biomass (sampling error in %)	Root biomass	Lying dead wood (sampling error in %)	Leaf litter (sampling error in %)	
Coast	59.83 (39.85)	10.12	n/a	n/a	69.95 (39.85)
Highlands	41.23 (20.11)	6.32	n/a	1.08 (22.4)	48.62 (30.12)
Accessible High Rainforest	838.77 (22.29)	111.46	55.79 (93.7)	6.56 (18.9)	1 022.58 (98.15)
High Rainforest of Difficult Access	282.40 (85.22)	36.97	16.34 (183.8)	3.48 (49.6)	339.18 (208.59)
Low Rainforest	11 010.76 (12.13)	1 353.38	581.08 (51.7)	71.19 (8.0)	13 016.41 (53.73)
Hydromorphic	1 389.50 (12.33)	179.43	21.96 (41.6)	23.36 (51.1)	1 614.24 (67.06)

Notes: sampling error at 95% confidence level; n/a: not applicable.
Source: Prepared by the authors.

TABLE 22.8

Results of the National Forest and Wildlife Inventory of Peru, Panel 1: forest area

Ecozone	Result (1 000 ha)	Sampling error (%)	Confidence interval [1] (1 000 ha)
Coast	3 721	25.39	2 776 – 4 665
Highlands	1 034	19.35	834 – 1 234
Accessible High Rainforest	5 769	19.28	4 657 – 6 881
High Rainforest of Difficult Access	1 697	75.24	420 – 2 973
Low Rainforest	37 273	11.32	33 054 – 41 492
Hydromorphic	7 368	10.93	6 563 – 8 174
Total	**56 862**		

Note: [1] 95% confidence level.
Source: Prepared by the authors.

22.7 IMPLEMENTATION AND QUALITY CONTROL

The entity in charge of NFWI implementation is the Ministry of Agriculture and Irrigation, through the Inventory and Valuation Directorate of the National Forest and Wildlife Service (Servicio Nacional Forestal y de Fauna Silvestre – SERFOR, according to its acronym in Spanish), in coordination with regional governments and other actors linked to the geographical area where the SUs are located.

Fieldwork is outsourced and supervised by SERFOR officials, who are responsible for planning activities, budgetary allocation, distribution of data collection, field crew training and quality control, in order to subsequently analyse the data to issue reports and briefings.

The contracted field crews record field data on printed forms, which are later digitised by the crews themselves using the Open Foris Collect software.

The quality control of the data collection is conducted by SERFOR officials in 10 percent of the total SUs assessed, according to the following three methods.

Internal check of the field crew

This verification is carried out by the field measurement crew, who review SU progress and the data collected in the field forms on a daily basis.

This quality control staff must ensure that each one of the variables defined in the field form is recorded and that the equipment is used properly.

Hot check in the field

The "hot check" is carried out by SERFOR staff who supervise the survey process of the first sampling unit assigned to the measurement crew, in order to ensure the accurate collection of data from the SU. The purpose of this check is to correct measurement errors or biases and to provide immediate corrective measures.

Cold check in the field

The "cold check", carried out by SERFOR staff, consists of a field verification of the data recorded in the forms by the crew tasked with assessing a given SU. This procedure verifies the quality of the data provided by the measurement crew, which will help to monitor and analyse the performance of the field staff who are conducting the inventories. The SUs to be reviewed with this procedure can be randomly selected or focused on the crews whose performance needs to be checked.

Desk checks

Databases and evidence collected in the field can also be checked; these are subject to the following quality control procedures:

- Verification of movements and access: through the verification of the records in the global positioning system (GPS) trackers distributed to field specialists.
- Data cleaning: involves the review of data and tables from fieldwork, which are organized by specialisation (flora, fauna, biometric data, necromass measurements and database construction). This procedure is used to address gaps due to omission, annotation errors, out-of-range data, logical errors and typing errors.
- Consistency analysis: aims to identify incorrect data and guide their resolution. In some cases, errors can be corrected in the office as soon as the concerned crew member is consulted after returning from the field. In other cases, they cannot be corrected.
- Verification of the photographic record: serves as information to support the data recorded in the field forms.

Desk checks are applied to 100 percent of the data received; they are carried out by a multidisciplinary team of professionals from SERFOR's Inventory and Valuation Directorate.

22.8 OTHER RELEVANT VARIABLES COLLECTED

The NFWI has a multipurpose approach, focused on the continuous updating of information on the status of forest products and services, the interactions of the people who benefit directly and indirectly from them, and the value of forests in their multiple functions, including climate change mitigation.

22.8.1. WILDLIFE REGISTER

The target population is all vertebrates of the bird, mammal, reptile and amphibian classes, which are identified with a scientific name at species level where possible. To this end, the data collection methodology is maintained on an opportunistic basis: during the access to the SU and while the assessment of forest condition attributes is being carried out. Thus, direct evidence (sightings or vocalisations) and indirect evidence (tracks, burrows, faeces, feathers, etc.) of the presence of fauna near the SU is recorded.

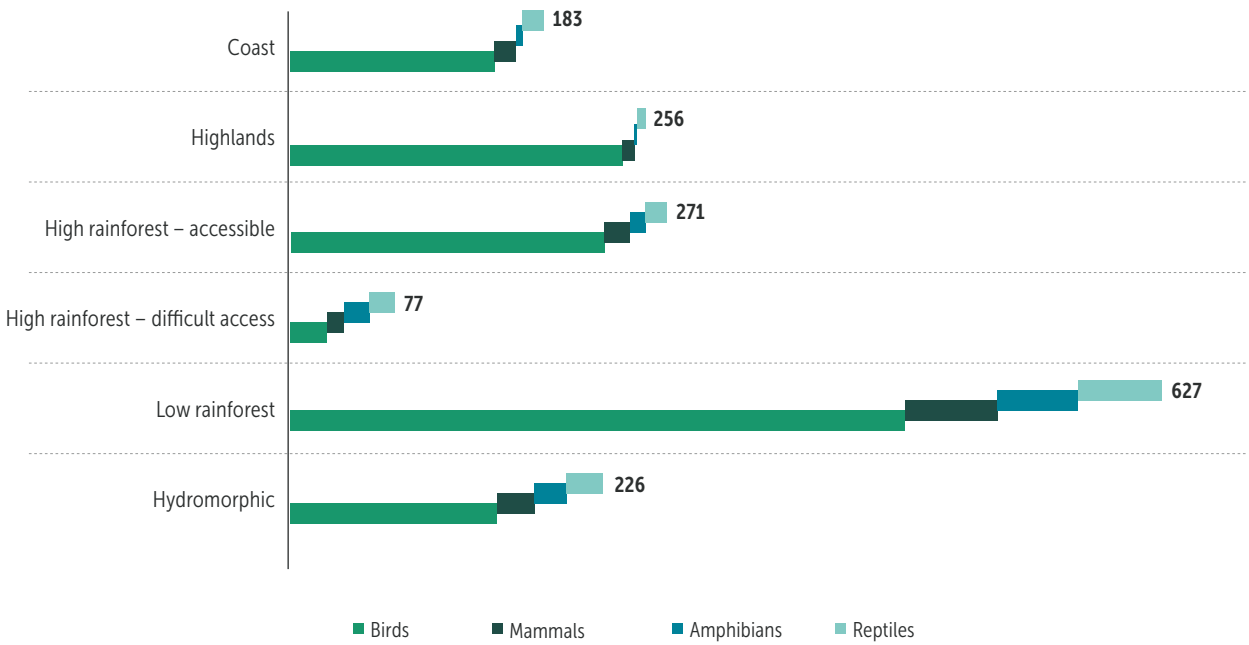
Records are considered more reliable if they are accompanied by a photograph or recording. However, indirect evidence is also recorded, such as *collpas* (clay licks), drinking or feeding troughs, bathing places, feathers, skins, skeletons, excreta, footprints or odours that may be useful in identification.

Due to time constraints and logistical requirements, the information collected is not intended to serve as a wildlife inventory. Nevertheless, these records are useful as they are generating a database of species occurrence in places that have not previously been reached. This is possible because of the comprehensive design of the SUs, which include as much evidence as possible in order to project the distribution of species for which in some cases no further information is available.

As results of NFWI Panel 1, Figure 22.6 shows that the greatest number of wildlife species are found in the Amazon region (Low Rainforest, Accessible High Rainforest, High Rainforest of Difficult Access and Hydromorphic ecozones) due to the high level of biological diversity known to exist in this region. The Low Rainforest ecozone has the highest number of species (a total of 627 birds, mammals, amphibians and reptiles); however, a lower diversity of wildlife is observed for the rest of the Amazon, which can be explained by the fact that the Low Rainforest ecozone had a considerably higher number of SUs assessed.

FIGURE 22.6

Number of wildlife species, by taxon, recorded in the National Forest and Wildlife Inventory of Peru, Panel 1



Source: Prepared by the authors.

Regarding the Coast and Highlands ecozones, there are more species recorded in the latter. This is because the Highlands, which cover 13 departments in the country, have a greater number of altitudinal levels; these create different ecosystems with a higher level of diversity than the Coast, which for Panel 1 has SUs for only three departments: Tumbes, Piura and Lambayeque.

It is interesting to note that the highest diversity of species for all ecozones corresponds to birds, as they tend to be more noticeable than mammalian, amphibian and reptile taxa.

22.8.2. SOCIOECONOMIC FOREST MONITORING

Socioeconomic forestry monitoring is the systematic collection of data on the relationship between the use and harvesting of forest resources and the socioeconomic aspects of the communities that benefit from the forests. It includes the way in which communities value their forests, conserve their resources, the products they use, their traditional knowledge, as well as aspects related to who makes decisions on resource management and how these decisions are made. The target populations are those that have a direct relationship with the forest due to their proximity and who benefit directly from forests, namely, the rural population centres. The unit of observation and analysis is the rural household.

Based on the information from the rural population centres, an area-based stratified cluster sampling probabilistic design was established, in which the strata correspond to the ecozones and the clusters correspond to the rural population centres, where rural households were selected. The rural population centres are made up of units between 10 and 100 families, with a population of more than 100 inhabitants, and which are located at a distance of less than 5 km from the SUs. Interviews were conducted with representatives of 10 households in each selected village.

The approach used for the design of the socioeconomic forest survey focuses on the consumption of goods and services (rather than production). It also covers the benefits generated from income and employment in the sector, which enable people to meet their needs through the consumption of goods and services.

Its thematic areas are:

- employment and household income;
- contribution of the forest to the household;
- forest harvesting dynamics;
- state of the forest;
- local people's participation in forest management.

In this way, the NFWI will collect and update information to develop public policies to facilitate good governance in forest management and better sustainable forest management practises, as well as better decision-making on how to manage the territory and forests. At the local level, the benefits will be passed on to native and rural communities with better policies to enable the sustainable development of their communities, maintaining their main food sources and other resources that contribute to improving present and future living conditions. In addition, the private sector will be better informed to develop new sustainable forestry business opportunities.

To date, socioeconomic data has been collected from the Coast, Highlands and Accessible High Rainforest ecozones; however, their analysis has not yet been reported.

22.9 FUTURE PROSPECTS

The NFWI provides information for planning the country's sustainable forest management, which is an overarching objective of the forest sector. It should be part of any climate change mitigation and adaptation policy with a holistic national approach, within the framework of national development and poverty reduction strategies.

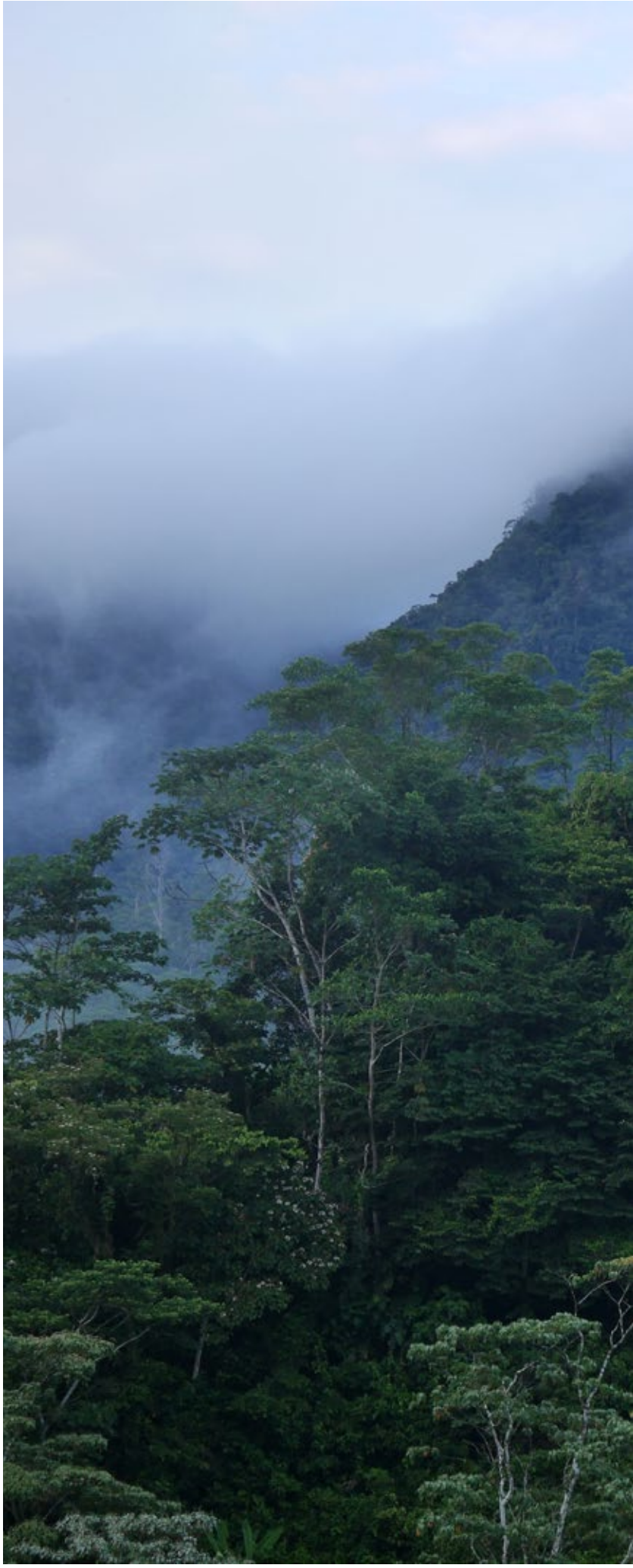
At the national level, certain legislation declares the implementation of the National Forest Inventory to be of national interest; this initiative is also part of the commitments made under the free trade agreement with the United States of America. However, this priority is not being supported through the timely allocation of state budget resources for the implementation of the NFWI. This is evidenced by the limited progress in its implementation. According to the methodological design, the sample organized in five panels should have been assessed in five years starting in 2013.

At the moment, Panel 1 has been completed and Panel 2 is 56 percent complete; very few financial resources have been allocated for operational expenses in the institutional annual plan.

An increasing number of users are demanding information from the NFWI, both from the public sector and as individual stakeholders. One example is forest zoning, a process that is being developed as a state policy, which uses NFWI field data to characterize the timber potential of forests. Likewise, the updating of the list of forest species and the list of threatened species of flora uses the geographic location data of the individual plants recorded in the field by the NFWI. The inventory's contribution to forest heritage research is also important, as it is used by students from universities in different countries who request NFWI data for their research.

Furthermore, the NFWI provides information for the development of the National Greenhouse Gas Inventory, the estimate of forest emission factors and the construction of the Forest Reference Level (FRL); these constitute important decision-making tools and contribute to the formulation of policies, strategies and development plans to reduce greenhouse gas emissions, and to the fulfilment of commitments made in the framework of international negotiations on climate change. Therefore, continuous improvement processes should be adopted in order to increase the transparency, consistency, comparability, completeness and accuracy of future inventories (for instance, provision of data with greater accuracy and less uncertainty, improvement of data collection systems, inter-institutional arrangements to ensure the financing of fieldwork, development and adaptation of methodologies to analyse inventory uncertainty, among others).

In this context, the Government of Peru should establish better coordination between the Ministry of Agriculture and Irrigation, the entity that provides the information, and the Ministry of the Environment, which is the focal point for the United Nations Framework Convention on Climate Change, in order to improve reports on the country's progress towards achieving low-carbon and climate-resilient development. This will enable a symmetrical distribution of the country's own resources and those from international cooperation agencies to support activity implementation and the institutional strengthening of government entities linked to forest ecosystem conservation.



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There is also a series of improvements in data collection and management of the information gathered that are expected to be implemented in the short term, as listed below:

- Implement the socioeconomic module of the NFWI on a larger scale, to understand the interrelationship and dynamics between the forest and the local population with access to it. This will provide information on the forms, methods and frequency of access to the forest, as well as the value of forest products and the benefits for families and local economies.
- Estimate results at the departmental level so that regional governments can apply sectoral policies with the support of SERFOR. These policies will focus on forest harvesting or conservation, depending on the status of the species and the priorities of the regional governments.
- Incorporate new variables into the data collection structure for forest monitoring, in accordance with possible climatic events, as well as the emergence of pests and population declines in forest species and wildlife, among others.
- Build new technological tools in forest inventory data collection through the use of electronic devices (notebooks, tablets), as well as equipment with smaller margins of error for measuring heights and diameters.
- Facilitate access to NFWI results. To this end, new interactive digital media should be considered, through which the user would be able to access the information obtained from the inventory.
- Strengthen the capacities of regional government experts by establishing regional technical groups for forest inventories.
- Develop predictive models of forest behaviour with forest inventory data, which could serve as a warning system in the event of unusual behaviour in any forest variable.
- Improve methodological and computer tools for field data processing and analysis by updating allometric equations for biomass estimates and using free software programmes for statistical analysis, among others.
- Optimize field data collection based on analyses that determine the optimal size of field measurement units, for example, determining the optimal length of the transect to calculate the carbon of the necromass of lying wood, among others.

In this scenario, Peru has shown interest in the harmonization of data among Latin American and Caribbean countries, with a view to comparing the results of the countries' national forest inventories and producing consistent regional statistics, along with the exchange of technical, scientific and technological knowledge between peers. This would also increase the visibility of NFIs, thereby stimulating their use in public policy decision-making which, in the short term, may pave the way towards increasing financial resources for their implementation.

It is also important to work on the harmonization of international agendas linked to natural resource management, such as the United Nations Framework Convention on Climate Change, the Convention on Biological Diversity, the United Nations Convention to Combat Desertification and the Sustainable Development Goals, among others.

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Chapter

PUERTO RICO AND UNITED STATES VIRGIN ISLANDS

FOREST INVENTORIES OF PUERTO RICO AND UNITED STATES VIRGIN ISLANDS

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23.1 PERIODIC INVENTORIES OF MAINLAND PUERTO RICO (1980–1990)

Prior to the late 1990s, the Forest Inventory and Analysis (FIA) Program, while nominally a national forest inventory, was implemented by the United States Forest Service regional Research Stations. During the time period described here, there were initially six separate regions which subsequently were consolidated into four regional stations: the Pacific Northwest, Rocky Mountains, Northern and Southern Research Stations. Then as now, the Southern Research Station (SRS) FIA Program was responsible for the forest inventories for Puerto Rico and the United States Virgin Islands. The SRS FIA conducted periodic forest inventories on an approximately ten-year cycle. Field crews worked as a group in one state for a year, completed measurements on all plots there, then moved to another state the next year. These field data were processed and reported on in a series of special Forest Service publications. These cyclic remeasurements continued from the late 1960s to the late 1990s, with each state in the southern United States of America being resurveyed three to four times. For a detailed history of the early years of the FIA Program, please refer to LaBau *et al.* (2007) and other programme documentation available at the national FIA Program website (www.fia.fs.fed.us/library/index.php).

Sampling points were located on a square grid that was approximately 4.8 kilometres (km) by 4.8 km, equivalent to 3 miles by 3 miles, or every 2 304 hectares (ha); however, this varied slightly over time, by region, and in some areas. Sampling intensity was increased in areas with forests of special economic interest, particularly the pine-growing coastal plains in the south-east. Field measurements were taken within a cluster of variable radius plots with subsampling for tree regeneration. Periodic forest inventories were conducted in Puerto Rico during this period, but not in the United States Virgin Islands. The methods used in Puerto Rico were simplified versions of those used in the southern states.

The first forest inventory in Puerto Rico was completed in 1980, the objective of which was consistent with the objectives of the forest inventory of the continental United States of America, that is, assessing the timber production potential of the island's forests (Birdsey and Weaver, 1982). Across the main island of Puerto Rico, 978 permanent sampling points were established along a square systematic grid at a spacing of 3.0 km by 3.0 km (1.9 miles by 1.9 miles, or every 900 ha) (see Table 23.1). This intensity was derived from sampling errors estimated from earlier fieldwork in Puerto Rico's forests (Birdsey and Weaver, 1982). The smaller, forested islands of Vieques, Culebra and Mona were not included in the inventory.

An island-wide estimate of forest area for commercial and non-commercial areas was made from aerial photographs, although coverage was incomplete. Permanent sample plots were installed in two of the six Holdridge life zones on the island (as described in Ewel and Whitmore, 1973) that were considered to have the potential for commercial timber production: the subtropical moist forests and subtropical wet forests. These two life zones included 437 sampling points, 133 of which were forested. The two life zones and four soil categories were used to stratify the plots. Areas excluded from the survey included public forests, floodplains, urban areas, mangrove forests, areas with poor soils, dry subtropical life zones, steep slopes (more than 60 percent), and critical watersheds with high rainfall, with the result that inventory plots were installed on only about half of the island's total land area.

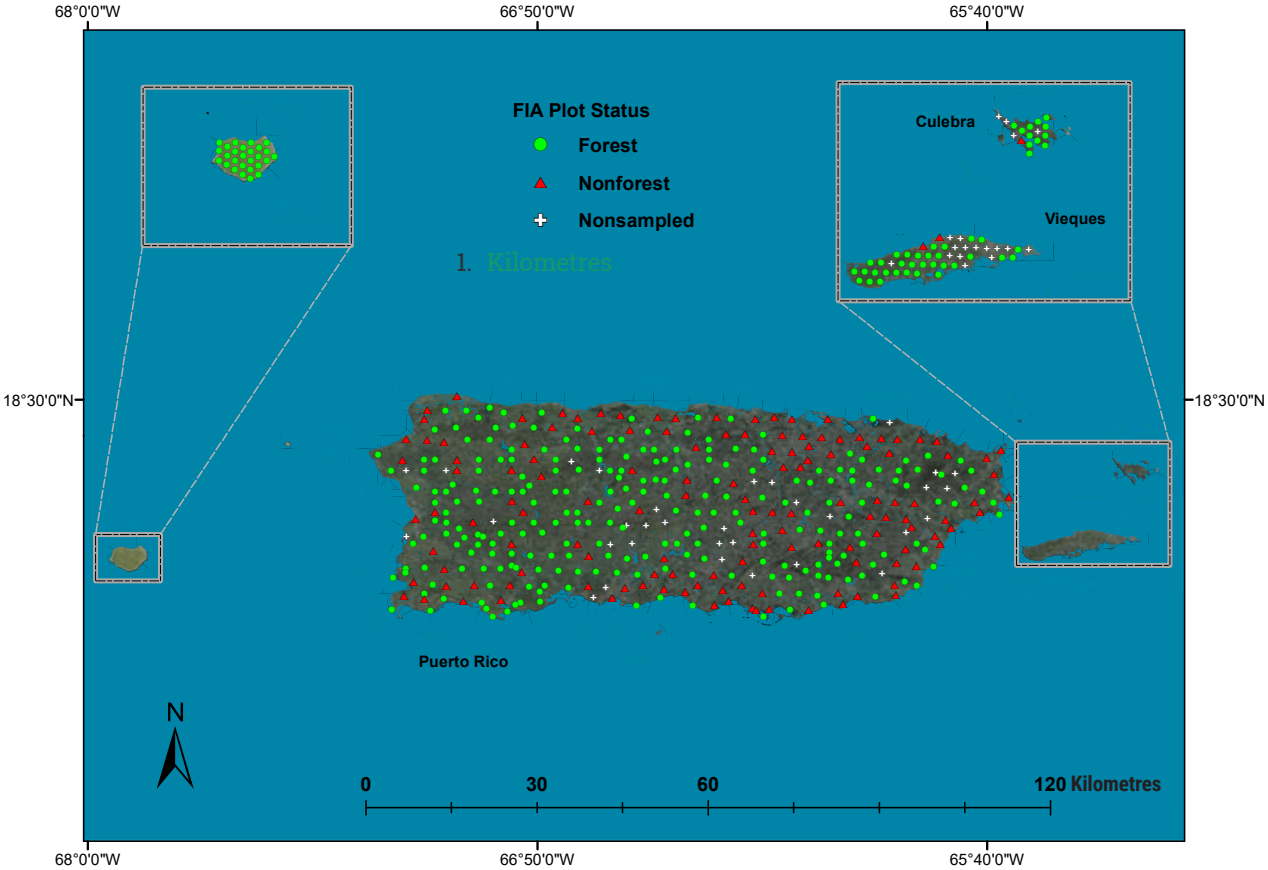
The field plots installed were a simplified variation of that used in the southern United States of America. A cluster of three variable-radius plots was established at each sample point location to measure trees with diameter at breast height (DBH) greater than or equal to 12.7 centimetres (cm). Each sample tree on the variable-radius plot represented 2.5 square metres (m^2) of basal area per hectare, or 0.83 m^2 of basal area per hectare when the plots were clustered. Trees less than 12.7 cm DBH were tallied within 3.6-metres (m) fixed-radius (approximately 40 m^2) plots centred around the variable-radius plot centres. Five years after the first inventory, the SRS FIA Program developed a more comprehensive estimate of forest area from newer, more complete aerial photographs of the entire island. Aerial photographic estimation of forest cover was expanded to include all forest types, except the montane forests and plantations. A subsample of the 1980 inventory plots installed in forest with commercial potential was revisited to update survey results (Birdsey and Weaver, 1987). The data collected during the survey update was expanded to include erosion factors, hydrology and operating conditions, as well as tree crown and branch measurements. The island's forests were resurveyed in 1990 using the previous surveys' updated methodology. The 437 permanent sample plots installed in 1980 were revisited to confirm their status, and 167 forested plots were measured (Franco, Weaver and Eggen-McIntosh, 1997).

23.2 ANNUALISED FOREST INVENTORY AND ANALYSIS INVENTORIES OF PUERTO RICO AND THE UNITED STATES VIRGIN ISLANDS, 2001–PRESENT

In the mid-1990s, the FIA Program transitioned to an annualised inventory design described in Brandeis (2003). Starting in 2001, the annualised FIA design was implemented in Puerto Rico with some modification to the sampling design, sampling intensity and field sampling unit (SU) layout, which are described in subsequent sections of this chapter and in Brandeis (2003) and Brandeis (2011) (see Table 23.1 and Figure 23.1). While some technical reviewers believed the FIA design would not adequately sample the highly diverse island forests due to the relatively small area sampled by each plot and the lack, at that time, of island-specific data collection, the FIA Program successfully adapted its National Forest Inventory (NFI) programme to the Caribbean island forests with relatively minor additions and modifications. Examples of these changes included land use and land cover class descriptors applicable to the islands, and volume and biomass equations for island tree species. The new systematic, annualised forest inventory design was applied to the United States Virgin Islands for the first time in 2004 (see Table 23.2 and Figure 23.2). The results from Puerto Rico NFI 3 are published in Brandeis, Helmer and Oswalt (2007); NFI 4 in Brandeis and Turner (2013); and NFI 5 in Marcano Vega (2019). Results of the first NFI of the United States Virgin Islands are published in Brandeis and Oswalt (2007) and NFI 2 in Marcano Vega (2020).

FIGURE 23.1

National Forest Inventory sampling design for Puerto Rico



The boundaries shown and the names and designations used on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any countries, territories, cities, areas, authorities, or delimitation of their frontiers or boundaries. Dotted lines on maps represent approximate boundaries for which there may not yet be full agreement.

Source: Adapted from **USDA (United States Department of Agriculture) Forest Service.** 2020. *Forest Inventory and Analysis National Core Field Guide. Vol. 1: Field data collection procedures for Phase 2 plots, Version 9.0.* Washington DC, USA, USDA Forest Service.

TABLE 23.1

Historical description of the National Forest Inventory for Puerto Rico

Inventory cycle	Execution period	Level	Sampling design	Number of sampling units
NFI 1	1980	National	Systematic	978
NFI 2	1990	National	Systematic	978
NFI 3	2001–2004	National	Systematic	514
NFI 4	2006–2009	National	Systematic	550
NFI 5	2010–2014	National	Systematic	574
NFI 6	2016–2019	National	Systematic	581

Source: Prepared by the authors.

TABLE 23.2

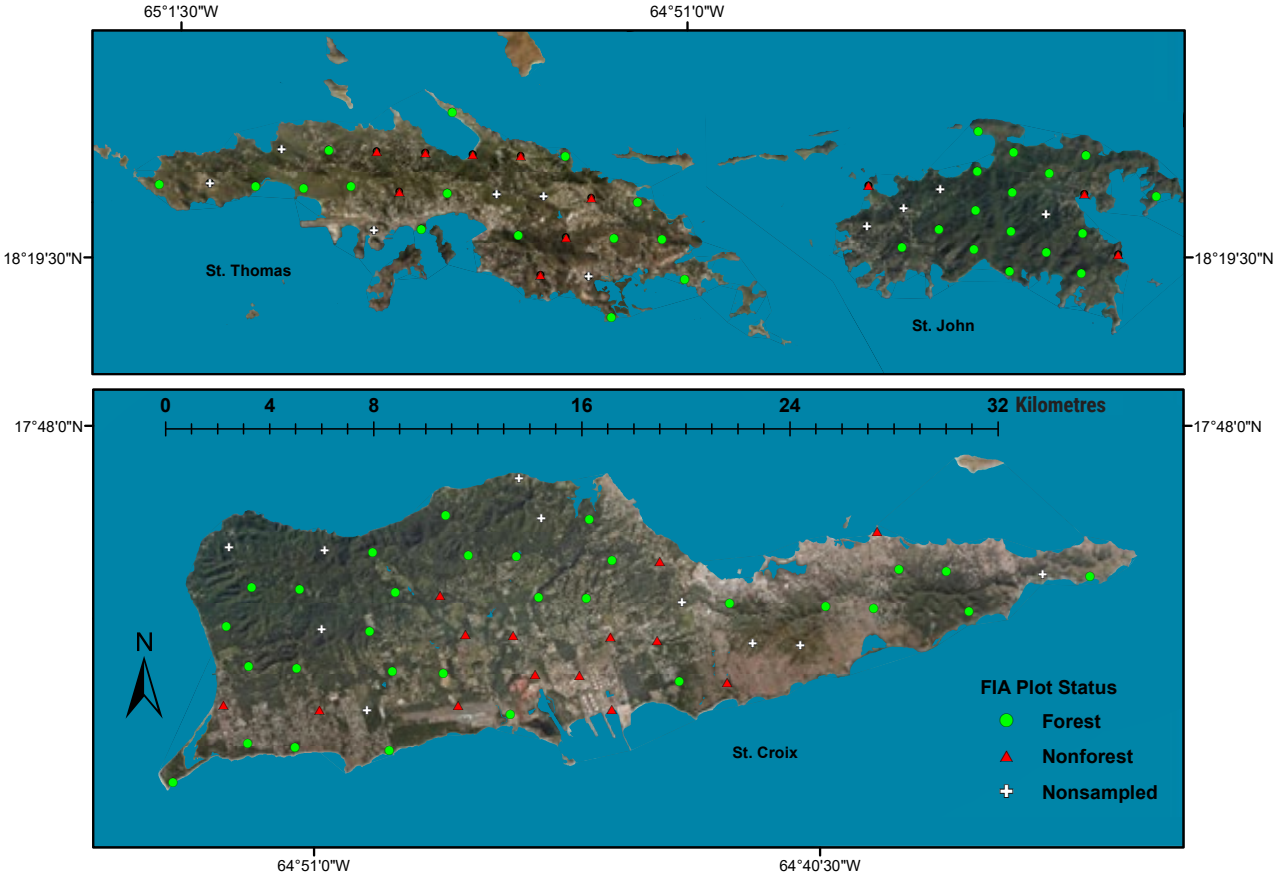
Historical description of the National Forest Inventory for the United States Virgin Islands

Inventory cycle	Execution period	Level	Sampling design	Number of sampling units
NFI 1	2004	National	Systematic	109
NFI 2	2009	National	Systematic	114
NFI 3	2014	National	Systematic	116
NFI 4	2019	National	Systematic	116

Source: Prepared by the authors.

FIGURE 23.2

National Forest Inventory sampling design for the United States Virgin Islands



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Source: Adapted from **USDA Forest Service.** 2020. *Forest Inventory and Analysis National Core Field Guide. Vol. 1: Field data collection procedures for Phase 2 plots, Version 9.0*. Washington DC, USA, USDA Forest Service..

23.3 TERMS AND DEFINITIONS

The FIA Program uses consistent definitions for forest land, volume and biomass across the entire geographic range of the United States of America and associated Commonwealths and Territories. Forest land is primarily defined by a minimum of 10 percent canopy cover of tree species, as defined in Table 23.3. Multiple quantitative methods can be used by field crews to determine whether the tree cover on a potential plot location reaches the minimum threshold. The choice of method depends on the degree of canopy cover and conditions at the potential plot site. (Details on these definitions and methods can be found in the FIA Database [FIADB] and Field Guide documentation available at www.fia.fs.fed.us/library/database-documentation/index.php and www.fia.fs.fed.us/library/field-guides-methods-proc/index.php, respectively).

One exception was made to the definition of forest land for the Caribbean islands. Normally, any human activities on the land which prevent natural forest regeneration would exclude that land from inclusion as forest. It was decided, however, that understorey agricultural systems that maintain the minimum tree canopy cover, such as agroforestry and shade coffee cultivation, would be included as forest land. However, these forest lands receive a special land use code so they can be differentiated from other forest lands.

The forest type definitions used by the United States Forest Service FIA Program to implement the NFI in Puerto Rico and United States Virgin Islands can be found in Table 23.3.

Individual tree measurements are used to calculate tree volume, biomass and carbon using a combination of volume equations, allometric equations and biomass expansion factors. Volume estimates are made for the main stem of the tree and can be expressed as gross or net volumes, as well as total cubic volume or volume sawn board feet. Biomass and carbon estimates are broken into multiple components. Oswalt and Conner (2011) and Woodall *et al.* (2011) provide more details on the methodologies used to make these estimates.

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TABLE 23.3

Summary of definitions used by the United States Forest Service Forest Inventory and Analysis Program to implement the National Forest Inventory in Puerto Rico and the United States Virgin Islands

Term	Definition	Variables and thresholds
Forest	**Accessible forest land –** Forest land has at least 10% canopy cover of live tally tree species of any size or has had at least 10% canopy cover of live tally species in the past, based on the presence of stumps, snags, or other evidence. Additionally, the condition is not subject to non-forest use(s) that prevent normal tree regeneration and succession, such as regular mowing, intensive grazing, or recreation activities. To qualify as forest land, the prospective condition must be at least 0.4 ha (1.0 acre) in size and 36 m (120.0 ft) wide measured stem-to-stem from the outer-most edge. Forested strips must be 36 m (120.0 ft) wide for a continuous length of at least 110 m (363.0 ft) in order to meet the acre threshold. Forested strips that do not meet these requirements are classified as part of the adjacent non-forest land. **Tree –** A woody perennial plant, typically large, with a single well-defined stem carrying a more or less definite crown; sometimes defined as attaining a minimum diameter of 7.6 cm (3 in) and a minimum height of 4.6 m (15 ft) at maturity.	**Ocular method –** The Ocular method is only used in areas that are obviously 0% live plus missing canopy cover or obviously greater than 10% live plus missing canopy cover. **Acre method –** If a condition is close to 10% canopy cover, and other methods may not accurately represent tree canopy cover due to irregular spatial distribution of tree canopies (e.g. clumpiness), the Acre method provides another estimate of the total tree canopy area within the radius of a 0.4-hectare (1-acre) plot located within the condition in question. **Subplot method –** To estimate cover using the subplot method, the crew measures the crowns of all live trees, seedlings and saplings on each of the four 0.017-hectare (1/24 acre) subplots.
Other wooded land	**Other wooded land –** Other wooded land has at least 5%, but less than 10%, canopy cover of live tally tree species of any size or has had at least 5%, but less than 10%, canopy cover of tally species in the recent past, based on the presence of stumps, snags, or other evidence. Other wooded land is recognised as a subset of non-forest land, and therefore is not currently considered a separate condition class.	See variables and thresholds for accessible forest land
Other land	**Non-forest land –** Land that has less than 10% canopy cover of tally tree species of any size (live + missing) and, in the case of afforested land, fewer than 375 established trees per hectare (150 per acre); or land that has sufficient canopy cover or stems, but is classified as non-forest land use (see criteria under present non-forest land use). Non-forest includes areas that have sufficient cover or live stems to meet the forest land definition, but do not meet the dimensional requirements.	See variables and thresholds for accessible forest land

TABLE 23.3 (CONTINUED)

Term	Definition	Variables and thresholds
Volume	**Volume** - A measure of the solid content of the tree stem used to measure wood quantity. *Gross board-foot volume* – Total board-foot volume of wood inside bark without deductions for total board-foot cull. *Gross cubic-foot volume* – Total cubic-foot volume of wood inside bark without deductions for rotten, missing, or broken-top cull. *Net board-foot volume* – Gross board-foot volume minus deductions for total board-foot cull. *Net cubic-foot volume* – Gross cubic-foot volume minus deductions for rotten, missing and broken-top cull.	Variables used for volume estimation for trees with DBH at least 12.7 cm (5 in): **Diameter at breast height (DBH)** - Unless one of the following special situations is encountered, measure DBH at 1.37 m (4.5 ft) above the ground line on the uphill side of the tree. **Diameter at root collar (DRC)** - For species requiring diameter at the root collar, measure the diameter at the ground line or at the stem root collar, whichever is higher. For these trees, treat clumps of stems having a unified crown and common root stock as a single tree. Use the following formula to compute DRC: $DRC = \sqrt{\sum_{i=1}^{n} Stem\ diameter_i^2}$ **Total length** - Record the total length of the tree, to the nearest 30 cm (1.0 ft) from ground level to the top of the tree. **Actual length** - record for trees with missing tops (top on live trees is completely detached; top on dead trees is greater than 50% detached from the tree). **Rotten/missing cull** - record the percent rotten or missing cubic-foot cull for all live tally trees greater than or equal to 12.7 cm (5.0 in) DBH/DRC and all standing dead tally trees greater than or equal to 12.7 cm (5.0 in).
Biomass	**Above-ground biomass (regional methodology)** - For the southern region, total above-ground biomass is estimated using allometric equations and is defined as the above-ground weight of wood and bark in live trees ≥ 2.5 cm (1.0 in) DBH/DRC from the ground to the tip of the tree, excluding all foliage (leaves, needles, buds, fruit and limbs < 1.3 cm (0.5 in) in diameter). Biomass is expressed as oven-dry weight and the units are tonnes. **Above- and below-ground biomass** - Nationally above-ground and below-ground biomass is estimated from each tree's sound volume using a Component Ratio Method that is consistently applied in all FIA regions. *Gross above-ground biomass* - Total tree biomass excluding foliage and roots with no deductions made for rotten, missing, or broken-top cubic-foot cull. *Net above-ground biomass* - Gross above-ground biomass minus deductions for missing cull, broken-top, and a reduction for a proportion of rotten cull for live or standing dead trees ≥ 12.7 cm (5.0 in) DBH. *Below-ground biomass* - Coarse roots only. Further, the total net above-ground biomass estimated using the Component Ratio Method is divided into the following components: *Top* - The portion of the main stem of a timber species tree above the 10.2 cm (4-inch) top diameter. *Branches* - All the branches of a timber species tree excluding the main stem. *Bole* – See: Merchantable stem. *Stump* – The portion of timber species below 30 cm (1-foot) to ground level.	See variables and thresholds for Volume. Regional biomass estimations are derived from allometric equations using DBH and actual length. Biomass estimations using the Component Ratio Method use a Biomass Expansion Factor applied to the Volume estimate for trees with DBH ≥ 12.7 cm (5 in) and allometric equations that use DBH and actual length for trees with DBH ≥ 2.5 cm (1 in) but < 12.7 cm (5 in).

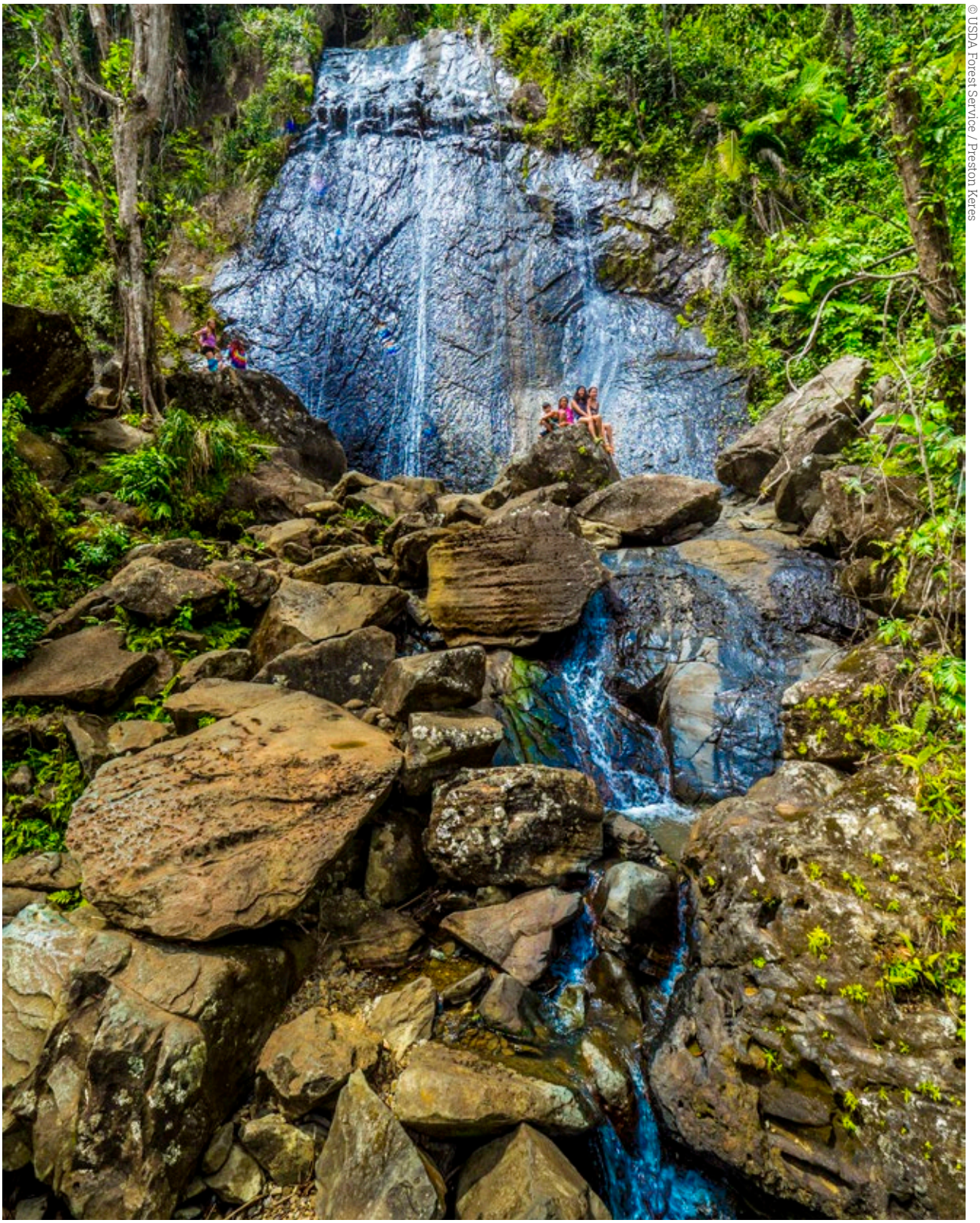
Source: **USDA Forest Service.** 2020. *Forest Inventory and Analysis National Core Field Guide. Vol. 1: Field data collection procedures for Phase 2 plots, Version 9.0.* Washington DC, USA, USDA Forest Service.; **Woudenberg, S.W., Conkling, B.L., O'Connell, B.M., LaPoint, E.B., Turner, J.A. & Waddell, K.L.** 2010. *The Forest Inventory and Analysis database: database description and user's manual version 4.0 for Phase 2.* General Technical Report RMRS-GTR-245. Fort Collins, USA, USDA Forest Service, Rocky Mountain Research Station.

TABLE 23.4

Forest types recognised by the United States Forest Service Forest Inventory and Analysis Program in Puerto Rico and the United States Virgin Islands

Island	Forest type	Forest type definition
Puerto Rico	Subtropical dry forest	Found in areas with 600 mm to 1 100 mm of annual precipitation. *Bursera simaruba* (L.) Sarg., *Bucida buceras* L., *Cephalocereus royenii* (L.) Britton, and *Guaiacum officinale* L. are species typical of Puerto Rican dry forest. The more heavily disturbed dry forest areas have numerous, smaller stemmed *Leucaena leucocephala* (Lam.) deWit, *Prosopis juliflora* (Sw.) DC., *Acacia macracantha* Humb. & Bonpl., and *Acacia farnesiana* (L.) Willd. individuals.
	Subtropical moist forest	Found in areas with 1 000 mm to 2 200 mm of annual precipitation. The subtropical moist life zone is the most extensive on Puerto Rico and covers a wide variety of soil parent materials, topographic classes and land uses that give rise to highly diverse species mixtures that typically include *Tabebuia heterophylla* (DC.) Britton, *Spathodea campanulata* Beauv., *Guarea guidonia* (L.) Sleumer, *Andira inermis* (W. Wright) Kunth ex DC., *Roystonea borinquena* O.F. Cook, *Mangifera indica* L., *Cecropia peltata* L., *Schefflera morototoni* (Aubl.) Maguire, Steyermark & Frodin, and species of the *Nectandra, Ocotea*, and *Coccoloba genera*.
	Subtropical wet and rain forest	Found in areas with 2 000 mm to 4 000 mm of annual precipitation. *Dacryodes excelsa* Vahl., *Sloanea berteriana* Choisy, and *Manilkara bidentata* (A.DC.) are species indicative of the tabonuco forest type. *Cecropia peltata* L., *Schefflera morototoni* (Aubl.) Maguire, Steyermark & Frodin, and *Ochroma lagopus* Sw. are also common in wet forest stands in early stages of succession or recovery from disturbance. Wet forest shade coffee plantations hold species such as *Guarea guidonia* (L.) Sleumer, *Inga laurina* (Sw.) Willd., *Inga vera* Willd., and *Erythrina poeppigiana* (Walp.) O.F. Cook. Palm forest characterized by *Prestoea acuminata* (Willd.) H.E. Moore var. montana (Graham) A. Hend. & G. Galeano occupies higher elevations falling in the subtropical rain forest zone.
	Lower montane wet and rain forest	Found in areas with elevations between 700 m and 1 000 m. Forest types and their typical species include the palo colorado forest type (*Cyrilla racemiflora* L., *Ocotea spathulata* Mez., *Micropholis chrysophylloides* Pierre, and *Micropholis garciniaefolia* Pierre), the elfin forest type (*Eugenia borinquensis* Britton, *Tabebuia rigida* Urban, *Weinmannia pinnata* L., and *Calycogonium squamulosum* Cogn.), and the palm brake forest type (*Prestoea acuminata* (Willd.) H.E. Moore var. montana (Graham) A. Hend. & G. Galeano).
	Mangrove forest	Mangrove forests comprised of *Rhizophora mangle* L., *Avicennia nitidia* Jacq., *Laguncularia racemosa* (L.) Gaertn. f., and *Conocarpus erectus* L. are found along the coastlines and estuaries.
	Non-stocked stands	Stands less than 10 percent stocked with live trees.
United States Virgin Islands	Subtropical dry forest	Found in areas with 600 mm to 1 100 mm of annual precipitation. Some of the native tree species that are common in subtropical dry forest in the United States Virgin Islands are gumbo limbo [*Bursera simaruba* (L.) Sarg.], torch wood (*Amyris elemifera* L.), Jamaican caper (*Capparis cynophallophora* L.), black manjack *(Cordia ricksecker*i Millsp.), water mampoo (*Pisonia subcordata* Sw.), lignum vitae (*Guaiacum officinale* L.), white frangipani (*Plumeria alba* L.), and fustic [*Pictetia aculeata* (Vahl) Urban]. The more heavily disturbed dry forest areas have numerous, smaller stemmed tan tan [*Leucaena leucocephala* (Lam.) deWit], *Prosopis juliflora* (Sw.) DC., stink kasha (*Acacia macracantha* Humb. & Bonpl.), and casha [*Acacia farnesiana* (L.) Willd.] individuals.
	Subtropical moist forest	Found in areas with 1 000 mm to 2 200 mm of annual precipitation. Some of the many natural indicator species of subtropical moist forest in the United States Virgin Islands include the dog almond [*Andira inermis* (W. Wright) Kunth ex DC.], black mampoo [*Guapira fragrans* (Dum.-Cours.) Little], yellow mombin (*Spondias mombin* L.), gre gre *(Bucida buceras* L.), sandbox tree (*Hura crepitans* L.), kapoktree [*Ceiba pentandra* (L.) Gaertn.], cigar box cedar (*Cedrela odorata* L.), bayrumtree (*Pimenta acemose* var. acemose), royal palm (*Roystonea borinquena* O.F. Cook) (on St. Croix only), stinkingtoe (*Hymanaea courbaril* L.), pumpwood (*Cecropia schreberiana* Miq.), and white cedar [*Tabebuia heterophylla* (DC.) Britt.]. While subtropical moist forests have some of the same introduced species found in subtropical dry forest, tamarind (*Tamarindus indica* L.) and genip (*Melicoccus bijugatus* Jacq.) are also commonly found.
	Mangrove forest	Mangrove forests comprised of *Rhizophora mangle* L., *Avicennia nitidia* Jacq., *Laguncularia acemose* (L.) Gaertn. F., and *Conocarpus erectus* L. are found along the coastlines and estuaries.
	Non-stocked stands	Stands with less than 10 percent stocking or canopy coverage of live trees.

Source: **Brandeis, T.J., Helmer, E.H. & Oswalt, S.N.** 2007. *The status of Puerto Rico's forests, 2003*. Resource Bulletin SRS-119. Asheville, USA, USDA Forest Service, Southern Research Station.



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23.4 SAMPLING DESIGN

The systematic sampling system for generating permanently monitored sampling points across the entire United States of America, associated Commonwealths and Territories replaces the regional square sampling grids used for the periodic forest inventories with a single hexagonal base grid built on the sampling frame of the Environmental Protection Agency's Environmental Monitoring and Assessment Program (White, Kimerling and Overton, 1992; Reams *et al.* 2005). The advantage of a hexagonal grid over square sampling grids is that hexagons could be more easily decomposed (divided into smaller hexagons) in multiples of 3, 4, 7, 9 and 11 until a desired sampling intensity was reached,

making it more flexible and versatile (Reams *et al.*, 2005). A hexagonal grid also has advantages over ones that use latitude and longitude to create a sampling grid because the sampled area remains consistent as meridians converge toward the Earth's poles, a key feature when sampling over such an extensive geographic range. The FIA Program needs a sampling scheme that would remain consistent on lands as far north as polar Alaska (24.5465° North) and as far south as American Samoa (14.2710° South), or St. Croix in the United States Virgin Islands (17.7246° North) in the northern hemisphere.

Nationally, the FIA Program uses as its base a sampling grid of one sampling point every 2 428 ha (6 000 acres) (Reams *et al.*, 2005). Each sampling point is systematically assigned to one of five interpenetrating panels with the intention of measuring all or half of the SUs within each panel annually. At the end of a five- or ten-year cycle, SUs from the first panel are remeasured and the cycle begins again.

The sampling intensity is increased to ensure an adequate sample, particularly on the smaller islands, while mainland Puerto Rico could potentially have an adequate sample with one sample point for every 2 428 ha if the objective was to produce very broad estimates at a strategic scale without making estimates for different forest strata. The 1980 periodic inventory sampled the island with a sampling point approximately every 900 ha, roughly an intensification of three times the new annualised sampling (Birdsey and Weaver, 1982). Rather than use this intensification across the entire island, which would have resulted in an oversampling of the more common subtropical moist forest and a potential undersampling of less common forest types like lower montane, it was decided to define potentially undersampled forest types using a Holdridge life zone map and then intensify sampling within those polygons. Lower montane forest, forests on serpentine soils, and subtropical dry forests received a sample intensification of 12 times the base grid.

Smaller islands also required sample intensification. The Puerto Rican island of Vieques was sampled at 9 times the base grid while the islands of Culebra and Mona each were sampled at 12 times the base grid. The United States Virgin Islands were sampled at 6 to 12 times the base grid.

Sampling points are distributed across four rather than five annual panels in Puerto Rico, and all SUs on the United States Virgin Islands are done in one year, making the latter a periodic inventory. The four-panel cycle allows for a year of special study work on Puerto Rico and doing all the work in the United States Virgin Islands simplifies the logistics of working there from the United States Forest Service's base in San Juan, Puerto Rico. Currently, transitioning the United States Virgin Islands to an annualised scheme is being considered as staffing and logistics concerns evolve.

The hexagonal base grid allows for the generation of highly intensive sampling grids in even smaller, special study areas. The United States Forest Service maintains a network of Experimental Forests and Ranges (EFRs) in which long-term ecological research is carried out, often with intensive forest monitoring. Sampling grids up to 36 times more intensive than the base grid (a sampling point every 67.4 ha) in EFRs (the Luquillo Experimental Forest on Puerto Rico and Estate Thomas on St. Croix) and commonwealth forests (Guánica, Toro Negro, Monte Guilarte and Carite) allow researchers to extrapolate findings from these intensively studied and monitored forests into the surrounding forests island-wide.

Where the percent canopy cover of tree species meets the 10 percent minimum and forest land use requirements described previously in Table 23.3, an NFI field measurement SU is installed at the sampling point. At the time of writing, the NFI in Puerto Rico and United States Virgin Islands did not sample trees in the category "Other land," that is, land which had less than 10 percent canopy cover of tree species or was of a non-forest land use (see Table 23.5).

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TABLE 23.5

Characteristics of the sampling design for Puerto Rico and the United States Virgin Islands as of 2019

Region/territory	Total area (1 000 ha)	Number of sampling units		
		Forest	Other wooded land	Total
Puerto Rico				
Puerto Rico	865 098	243	243	486
Vieques	13 431	33	19	52
Culebra	3 359	12	5	17
Mona	5 581	26	0	26
Subtotal	887 469	314	267	581
United States Virgin Islands				
St. Croix	21 375	30	31	61
St. John	4 895	16	7	23
St. Thomas	6 980	15	17	32
Subtotal	33 251	61	55	116
Total	**920 720**	**375**	**322**	**697**

Source: Prepared by the authors.

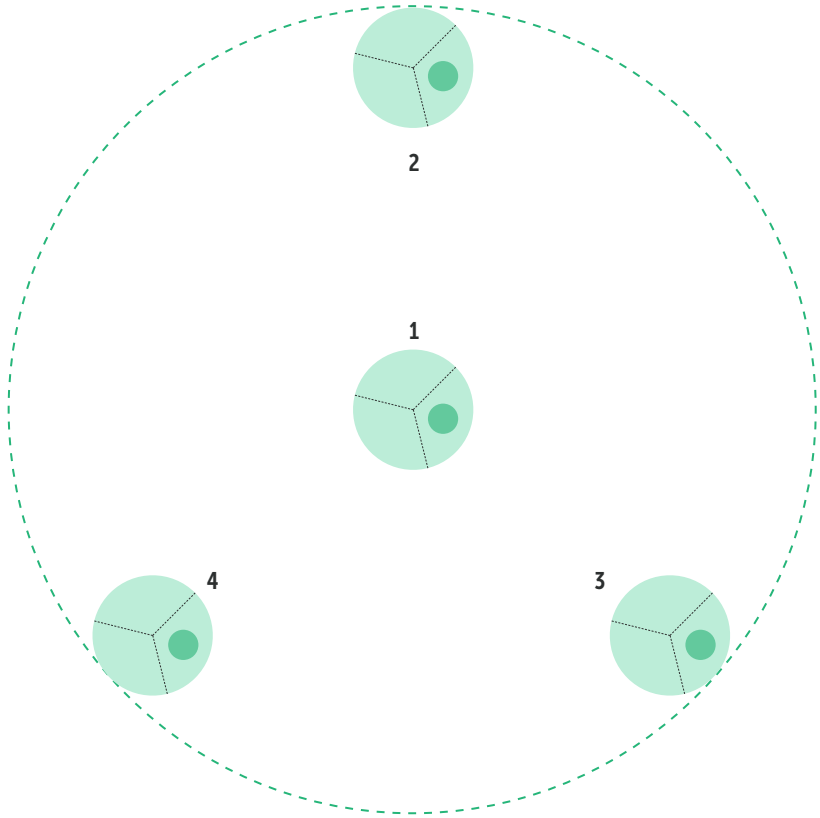
23.5 SAMPLING UNIT DESIGN

The nationally consistent FIA plot design consists of a four-plot cluster (Figure 23.3). Each circular plot in the cluster has a 7.3 m radius, making each plot 0.017 ha (one twenty-fourth of an acre), giving a total sampled area of 0.067 ha (one-sixth of an acre) (Bechtold and Scott, 2005). There are 36.6 m between the centres of each plot, so the total SU footprint roughly encompasses an area of 0.40 ha (1 acre). Sampling unit and area descriptions are made on all SU, such as location (coordinates and political descriptions), slope, elevation, forest type, ownership, stand size class and many other descriptors relevant to the NFI. For details on the data collected, see USDA Forest Service (2020). All trees within the subplots with a DBH (measured at 1.37 m) greater than or equal to 12.7 cm are identified and measured. Additional variables describe each tree's health, presence of damages, and quality in terms of timber production. Field crews identify and measure all saplings with a DBH between 2.5 cm and 12.6 cm within a 2.1 m radius subplot nested within each plot. They also identify and count all seedlings with a height greater than or equal to 30 cm within the subplot. The elimination of multiple regional SU designs and regionally specific data collection greatly simplified field guide documentation and field crew training.

In addition to the standard NFI sample SU data collection described above, a series of additional data collection protocols that are used to assess and monitor forest health can be implemented on the FIA plot footprint. Field guides and processing routines have been developed to assess forest soils, down woody materials, crown condition and health, understorey vegetation and forest lichen diversity.

FIGURE 23.3

Sampling unit configuration of the National Forest Inventory used by the United States Forest Service Forest Inventory and Analysis Program in Puerto Rico and the United States Virgin Islands



	Area	Dimensions
Subplot	0.042 ac (0.01681 ha)	24 ft (7.3 m) radius
Microplot	0.003 ac (0.0013 ha)	6.8 ft (2.1 m) radius
Cluster plot	1.495 ac (0.6050 ha)	144 ft (43.9 m) radius
Down woody debris transects		

Source: **USDA Forest Service.** 2020. *Forest Inventory and Analysis National Core Field Guide. Vol. 1: Field data collection procedures for Phase 2 plots, Version 9.0.* Washington DC, USA, USDA Forest Service.

23.6 CALCULATION OF LAND AREA, VOLUME AND BIOMASS

The processing of NFI data collected in Puerto Rico and the United States Virgin Islands is consistent with that used by the FIA Program nationally. Extensive, detailed documentation of these procedures and systems can be found at the FIA Library website (www.fia.fs.fed.us/library/sampling/index.php), as well as in numerous other publications. Key features include the use of portable data recorders (PDRs) for data collection in the field, digital transmission of data from field locations to central servers, a national data processing and storage system, and publicly accessible database with the NFI results.

Data are collected in the field with rugged PDRs using customised software, the Mobile Integrated Data Acquisition System (MIDAS), which features screens and fields that emulate paper tally sheets. At the start of the field season, field crew members download the list of SU they are assigned to measure from the FIA servers to their PDRs. For SU that have been previously measured, past information is also downloaded. As data are being collected on the plot, the programme has numerous range and logic checks to assist with data quality assurance.

Once data are collected on a SU, they are transmitted via the internet to FIA servers. From there, data are loaded into the National Information Management System (NIMS) for processing and storage within an Oracle relational database. Various estimation procedures are performed by modules run on the field collected data to generate calculated values like tree volumes, biomass and carbon, as well as to calculate the expansion factors that will be used to expand tree and SU values into population estimates. Some NIMS modules needed considerable expansion to incorporate the forest inventories of these Caribbean islands, principally the master tree species list and references to the volume, biomass and carbon equations to be applied for each species. It was necessary to add all tree species that could potentially be found on these Caribbean islands to this species' reference table. The United States Department of Agriculture's (USDA) Plant List of Accepted Nomenclature, Taxonomy and Symbols (PLANTS) database (https://plants.sc.egov.usda.gov/) was used as the definitive taxonomic authority and nomenclature source. Prior to the addition of the Caribbean tree species (and later additions of Pacific Islands and urban tree species), there were approximately 380 tree species in the NIMS species reference table. Incorporating the Caribbean islands into FIA meant adding over 870 new tree species to this table.

The FIA Program uses data from a spatially balanced sample of inventory SUs to estimate various forest parameters, including forest land area and tree attributes such as volume and number of trees. The inventory was designed to produce acceptably precise estimates of key parameters for relevant geographic areas (subpopulations), which are termed estimation units. These include states, multicounty areas, National Forests, or other areas of interest. Estimation is based on a finite population paradigm and design-based inference. Post-stratification, typically using strata formed from categorical maps based on remote sensing data, is used to improve the precision of estimates (Scott *et al.*, 2005). Stratum maps are formed in various ways in different regions, but generally are based on maps of land cover (canopy cover proportions or forest/non-forest designation). They can also include other maps such as ownership or other wall-to-wall layers. The post-stratification process involves labelling each SU with its stratum identity based on geographic location, calculating stratum means and variances from SU-level values, and using stratum weights (from the stratum area proportions within the estimation unit) to create weighted, combined estimates for the attribute and its variance within the estimation unit (Scott *et al.*, 2005). In Puerto Rico, categories of forest cover for post-stratification are derived from the National Land Cover Database (USGS, 2016), a national land cover map made from satellite imagery. As this land cover map does not include the United States Virgin Islands, simple random sampling is used there, rather than post-stratification.

Prior to estimation, raw data are analysed for errors and processing steps are applied, such as calculation of computed variables like tree volume and biomass, as well as adjustments to handle nonresponse. One component of the estimation process is the generation of SU-level values from the constituent data elements. For example, plot-level totals of tree volume per acre or number of trees per acre, as well as proportion of different land type classes, are generated. Land type proportions are calculated by mapping the areas of various land type variables (ownership, land cover, land use, stocking class, etc.) on each plot. These plot-level totals are used to generate means at the stratum and estimation unit level, as described above; these mean values are then multiplied by the known areas of the estimation units to arrive at values for total amounts of each attribute.

Individual tree volume, biomass and carbon are estimated using the standard FIA national methodology and suites of equations documented in Oswalt and Conner (2011) and Woodall *et al.* (2011). Essentially, inside bark tree volumes are estimated using a conventional linear regression model. This is the net volume of wood in the central stem of a sample tree with a diameter of 12.7 cm of more, from a 30-cm stump to a minimum 10-cm top diameter outside bark (DOB), or to where the central stem breaks into limbs all of which are less than 10 cm DOB. With few exceptions, Caribbean species' volume is estimated using two generic equations for non-commercial hardwoods and unknown conifers (tree species for which genus or species-level equations were never developed) found in the south-eastern continental United States of America (Table 23.6). Additional Caribbean island-specific biomass equations were derived from published literature with preference given to those that were developed from data collected in Puerto Rico (see references in Tables 23.6 and 23.7). Subtropical dry forest biomass allometric equations were lacking, thus some destructive sampling and equation development was done and documented in Brandeis *et al.* (2006) (Table 23.7).

TABLE 23.6

Equations used for predicting total stem volume in Puerto Rico and the United States Virgin Islands

Species group	Equation	Source
Eastern non-commercial hardwoods	$V = 0.062125 + 0.002494\ (D_{bh}^2\ H_T)$	Oswalt and Conner (2011)
Miscellaneous conifers	$V = 0.065755 + 0.002813\ (D_{bh}^2\ H_T)$	Oswalt and Conner (2011)

Notes: Net volume of wood in the central stem of a sample tree is greater than or equal to 12.7 cm diameter, from a 30-cm stump to a minimum 10-cm top diameter outside bark (DOB), or to where the central stem breaks into limbs all of which are less than 10 cm DOB. V = total stem volume (in cubic feet); Dbh = diameter in inches at 1.37 metres; HT = total tree height in feet.

Source: **Oswalt, C.M. & Conner, R.C.** 2011. *Southern forest inventory and analysis volume equations user's guide.* General Technical Report SRS-138. Asheville, USA, USDA Forest Service, Southern Research Station.

TABLE 23.7

Equations used for predicting above- and below-ground biomass in Puerto Rico and the United States Virgin Islands

Forest life zone or species	Equation	Source
Lower montane wet and rain forest	$AGB = 4.7962 + 0.0310 \times D_{bh}^2\ H_T$	Weaver and Gillespie (1992)
Subtropical wet and rain forest	$AGB = e^{(0.950 \times lnD_{bh}^2\ H_t\ -\ 3.282)}$	Scatena *et al.* (1993)
Subtropical moist forest	$AGB = e^{(-1.71904 + 0.78214 \times ln\ D_{bh}^2 + H_t)}$	Brandeis *et al.* (2006)
Subtropical dry forest	$AGB = e^{(-1.94371 + 0.84134 \times ln\ D_{bh}^2 + H_t)}$	Brandeis *et al.* (2006)
***Bucida buceras*, all forest-type groups**	$AGB = e^{(-1.76887 + 0.86389 \times ln\ D_{bh}^2 + H_t)}$	Brandeis *et al.* (2006)
***Prestoea montana*, all forest-type groups**	$AGB = 10.0 + 6.4 \times H_T$	Frangi and Lugo (1985), Brown (1997)
***Rhizophora mangle*, mangrove**	$AGB = \left[125.957 \times (D_{bh}^2\ H_T^{0.8557})\right] / 1000$	Cintrón and Schaeffer-Novelli (1984)
***Laguncularia acemose*, mangrove**	$AGB = \left[70.0513 \times (D_{bh}^2\ H_T^{0.9084})\right] / 1000$	Cintrón and Schaeffer-Novelli (1984)
***Avicennia germinans*, mangrove**	$AGB = 0.14 \times D_{bh}^{2.4}$	Fromard *et al.* (1998)
Below-ground biomass, all forest types	$BGB = e^{(-1.0587 + 0.8836 \times ln\ (AGB))}$	Cairns *et al.* (1997)

Notes: Above-ground biomass is in oven-dry kilograms of all live above-ground tree parts, including stem, stump, branches, bark, seeds and foliage, as estimated from regression equations that predict above-ground biomass from individual tree diameter at breast height and total height measurements. Below-ground biomass is also in oven-dry kilograms of all live below-ground tree parts, as estimated from a regression equation modelling the relationship between above-ground biomass and below-ground biomass (Cairns *et al.*, 1997). AGB = above-ground biomass in oven-dry kilograms; D_{bh} = diameter in centimetres at 1.37 metres; H_T = total tree height in metres; BGB = below-ground biomass in oven-dry kilograms.

Source: **Brandeis, T.J., Delaney, M., Parresol, B.R. & Royer, L.** 2006. Development of equations for predicting Puerto Rican subtropical dry forest biomass and volume. *Forest Ecology and Management*, 233(1): 133–142.; **Brown, S.** 1997. *Estimating biomass and biomass change in tropical forests: A primer.* FAO Forestry Paper 134. Rome, FAO.; **Cairns, M.A., Brown, S., Helmer, E.H. & Baumgardner, G.A.** 1997. Root biomass allocation in the world's upland forests. *Oecologia*, 111: 1–11.; **Cintrón, G. & Schaeffer-Novelli, Y.** 1984. Características y desarrollo estructural de los manglares de Norte y Sur América. *Ciencia Interamericana*, 25: 4–15.; **Frangi, J.L. & Lugo, A.E.** 1985. Ecosystem dynamics of a subtropical floodplain forest. *Ecological Monographs*, 55(3): 351–369.; **Fromard, F., Puig, H., Mougin, E., Marty, G., Betoulle, J.L. & Cadamuro, L.** 1998. Structure, above-ground biomass and dynamics of mangrove ecosystems: new data from French Guiana. *Oecologia*, 115: 39–53.; **Scatena, F.N., Silver, W.L., Siccama, T., Johnson, A. & Sanchez, M.J.** 1993. Biomass and nutrient content of the Bisley Experimental Watershed, Luquillo experimental Forest, Puerto Rico, before and after Hurricane Hugo, 1989. *Biotropica*, 25(1): 15–27.; **Weaver, P.L. & Gillespie, A.J.** 1992. Tree biomass equations for the forests of the Luquillo Mountains, Puerto Rico. *Commonwealth Forestry Review*, 71(1): 35–39.;

Once new data are processed, sets of population estimation tables are produced for review by FIA analysts and selected stakeholders. If no problems are found, the data are posted to the publicly accessible FIADB where online tools allow users to query the data and generate forest resource tables and maps (links to which can be found at www.fia.fs.fed.us/tools-data/). The FIA database documentation and population estimation procedures are available at the national FIA library website (www.fia.fs.fed.us/library/database-documentation/index.php#FIADB).

23.7 RESULTS OF THE MOST RECENT NATIONAL FOREST INVENTORY

The results presented in this section are based on the sixth and most recent forest inventory (2016–2019) in Puerto Rico, and the third forest inventory (2014) in the United States Virgin Islands.

After a phase characterized by a high rate of forest cover increase in Puerto Rico, shown by the forest inventories executed from 1980 to 2004 (31.3 percent to 52.8 percent of total land area), the archipelago has transitioned to a phase of forest cover steadiness since 2004 (Marcano Vega, 2019). Nevertheless, forest structural changes during the period of 2004 to 2019 show that stands in Puerto Rico increased in net volume, live tree above-ground biomass, and live tree carbon. This trend indicates a tendency towards mature stages of development within the secondary stands that typically characterize Puerto Rican forests. Nevertheless, between the last two inventories in Puerto Rico, forest stand volume and live tree biomass and carbon remained relatively stable. This is noteworthy considering the passage of hurricanes Irma and María through Puerto Rico during September 2017. Continuous monitoring will determine if forest structure will eventually change, considering that some stems that were structurally affected by the storms showed lower foliage densities than pre-hurricane values that are considered as normal to support their wood biomass.

The total forested land estimated for Puerto Rico was 467 320 ha in 2019, representing a forest cover of 52.7 percent of the archipelago. This forest cover is associated with a net volume (trees at least 12.5 cm DBH) of 38.28 million cubic metres of wood and a biomass of 37 546 460 oven-dry tonnes of above-ground biomass (live trees at least 2.5 cm DBH). Values of live tree above- and below-ground carbon (trees at least 2.5 cm DBH) show 22 482 140 tonnes stored in the forests of Puerto Rico (Table 23.8).

In the United States Virgin Islands, the overall forest area has been relatively stable since the first forest inventory, but forest stands increased in net volume, live tree above-ground biomass, and live tree carbon during the period of 2004 to 2014. Although this suggests, as is the case of Puerto Rico, a trend towards mature stages of development within forest stands, the ongoing fourth forest inventory of the United States Virgin Islands will enable us to interpret if the passage of hurricanes Irma and María resulted in a meaningful effect on the current status of the United States Virgin Islands' forests.

The total forested land estimated for the United States Virgin Islands was 19 010 hectares in 2014, representing a forest cover of 57.2 percent of total land area. Values of net volume of live stems show a total of 0.59 million cubic metres of wood and values of biomass show 919 500 oven-dry tonnes of above-ground biomass. Values of live tree above- and below-ground carbon show 554 850 tonnes stored in the forests of the United States Virgin Islands (Table 23.9).

23.8 IMPLEMENTATION AND QUALITY CONTROL

The FIA Program has Quality Assurance and Quality Control (QA/QC) procedures in place all through the programme and particularly along the flow of data from field to database, details of which can be found in the Quality Assurance Fact Sheet (Pollard, n.d.). All of these national FIA procedures are applied to data collected in Puerto Rico and the United States Virgin Islands. Formal management procedures guide programme development, national standardization and proposed changes. The programme makes publicly available documentation of field guides, database structure, estimation procedures, etc. to ensure transparency. Field crew members must undergo training and pass testing for certification before being allowed to collect data for the FIA Program.

Currently, the FIA Program nationally has a gender distribution of 72 percent men and 28 percent women. For the southern region, under which responsibility for the Puerto Rico and United States Virgin Islands

TABLE 23.8

Results of the National Forest Inventory for Puerto Rico (2019)

Variable	Result (percent sampling error)	Description
Area	467.32 ± 16.40	Forest land, thousand hectares
Volume	38.28 ± 2.80	Million cubic metres, in trees at least 12.5 cm diameter at breast height (DBH)
Biomass	37 546.46 ± 2 402.97	Live tree above-ground biomass, thousand oven-dry tonnes, in trees at least 2.5 cm DBH
Carbon	22 482.14 ± 1 434.36	Live tree above- and below-ground carbon, thousand tonnes, in trees at least 2.5 cm DBH

Note: with 68 percent confidence intervals

Source: Prepared by the authors

TABLE 23.9

Results of the National Forest Inventory for the United States Virgin Islands (2014)

Variable	Result (percent sampling error)	Description
Area	19.01 ± 1.65	Forest land, thousand hectares
Volume	0.59 ± 0.11	Million cubic metres, in trees at least 12.5 cm diameter at breast height (DBH)
Biomass	919.50 ± 111.90	Live tree above-ground biomass, thousand oven-dry tonnes, in trees at least 2.5 cm DBH
Carbon	554.85 ± 67.19	Live tree above- and below-ground carbon, thousand tonnes, in trees at least 2.5 cm DBH

Note: with 68 percent confidence intervals

Source: Prepared by the authors

inventory falls, the distribution is 83 percent men and 17 percent women. The three-person field crew that works in the islands consists of two men and one woman, plus one male analyst.

In the field, there is a robust system of PDR error, logic and range checks designed to minimize the recording of erroneous data while production crew members are still on the plot. After field data collection, FIA's goal is to have experienced field cruisers acting as auditors visit up to 8 percent of the plots. Measurements of continuous data such as DBH, tree height, azimuth and distance to trees are evaluated based on percent attainment of measurement quality objectives presented in the FIA field guide. Statistical significance of differences (bias) is tested between auditors and production crews. Some field check visits are done by the auditors with the production crews present with the objective of providing immediate feedback and supplemental training; these are called "hot checks." "Cold checks" are visits by the auditors without the production crew present, but with the data they collected. This process controls the quality of the data being collected by the production crew and the information gained is used to propose improvements to their work. When the auditors revisit a completed plot without the data from the production crew, called "blind checks", this provides an estimate of the measurement of uncertainty and information on the repeatability of the variables themselves that can be used to continually improve the programme.

Before the field collected data can be transmitted to the FIA database, it undergoes another series of automated and manual checks. Questionable data are flagged for further examination. Changes to the data are only made when the cause for the error is obvious (transposed numbers, for example) and easily fixed. As a matter of policy, however, changing or discarding data is very rarely done. Once all the data have passed the checks, they are processed, and population estimates produced. Sets of review tables are generated for review by resource analysts and key partners familiar with these forests before their final validation and release for public access.

23.9 OTHER RELEVANT VARIABLES COLLECTED

Supplemental data collection protocols have been designed to address special forest structural characteristics and the need for detailed information on forest regeneration, as well as to allow for more in-depth monitoring of forest health indicators. While these supplemental protocols are not implemented on all plots at all times, they can be applied when circumstances call for them and resources are available. Each data collection addition has a fully developed field guide, PDR programme, database tables and processing algorithms and population estimation procedures already in place and ready for implementation.

In forests where large diameter, widely spaced trees are prevalent, ensuring an adequate sample of these requires expanding the total sampled area within each subplot. The subplot radius is expanded to 17.9 m (58.9 ft) to capture more trees with diameters greater than 60 cm. At the opposite end of the size spectrum, another set of expanded data collection protocols capture more detailed information on tree seedlings found within the nested regeneration microplots within each of the four subplots.

The supplemental forest health monitoring data collection protocols include those for down woody materials, tree crown condition assessment, lichen survey, forest floor and soil sampling, full vascular plant survey and a more simplified understorey vegetation assessment focused primarily on structural characteristics and the predominant plant species present. In Puerto Rico and the United States Virgin Islands, down woody materials data are regularly collected on a subset of the forested plots and have also been collected on plots recently impacted by hurricanes as part of special studies. Soil sampling has been done on this same subset in 2001 but these data are no longer collected. Full vascular plant surveys have been done in two special study areas, the Virgin Islands National Park on St. John, United States Virgin Islands, in conjunction with a neotropical migrant bird survey (Oswalt, Brandeis and Dimick, 2006) and the Mona Island Nature Reserve, Puerto Rico (Brandeis, Meléndez-Ackerman and Helmer, 2012).

The FIA Program also has protocols for conducting urban tree inventories currently applied to cities in the mainland United States of America. Early versions of this data collection and plot remeasurement within the San Juan Bay watershed's estuary (which encompasses most of metropolitan San Juan, Puerto Rico) are described in Brandeis *et al.* (2014). Planning is underway for a third measurement of San Juan's urban trees with a new, expanded sampling design. The next forest inventory for the United States Virgin Islands will be done using a combination of the previously implemented NFI methods plus urban forest inventory methods on those sampling points that do not meet the minimum tree canopy cover (10 percent) or land use requirements for a forest inventory plot. This will provide the first inventory of trees on all lands for those islands.

23.10 FUTURE PROSPECTS

The prospects for the NFIs in Puerto Rico and the United States Virgin Islands are promising because they are providing unique and valuable information with each remeasurement. The public availability of the data, its compatibility with FIA data collected everywhere in the United States of America and its territories, transparent methodology, extensive, detailed documentation, and the availability of technical assistance and data interpretation have contributed to a growing, diverse number of FIA data users. Still, improvements can be made to increase the NFIs' value even more, particularly relating to the impacts on and vulnerability of Caribbean forest ecosystems to climate change.

Growth rates of most of the Caribbean subtropical species measured by these NFIs had never been quantified before (Brandeis *et al.*, 2006). Now, the FIA Program needs to improve on the subtropical tree species volume, biomass and carbon equations so that it does not rely so heavily on generic equations for its carbon storage and sequestration estimates. The NFI also needs to increase in both frequency and sampling intensity its monitoring of understorey and forest floor carbon pools and how they respond to disturbances like hurricanes and wildfires. The ability to monitor forest vegetation community dynamics also needs to be strengthened with a greater implementation of non-tree vascular plant surveys. Expansion to include trees in non-forest areas like urban and agricultural lands will be vital in the future. Large portions of these islands are densely populated and land uses are spatially complex and fragmented. Failing to capture the trees in these non-forest areas greatly underestimates the ecosystem services they provide island populations.

The FIA Program must also make greater use of remotely sensed imagery and ancillary data sources to supplement and strengthen the current NFI assessments. High resolution satellite imagery can offer more detailed "wall-to-wall" coverage by extrapolating from the on-the-ground FIA plot network. This imagery can also help provide better estimates in smaller areas with inadequate numbers of FIA plots, or areas whose shapes are challenging to sample well with the FIA grid-based sampling system, such as mangrove forests, riparian areas and mountain tops.

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Chapter

DOMINICAN REPUBLIC

NATIONAL FOREST INVENTORY OF THE DOMINICAN REPUBLIC

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24.1 HISTORICAL OVERVIEW OF NATIONAL FOREST INVENTORIES

In 1972, the Food and Agriculture Organization of the United Nations (FAO) conducted the first National Forest Inventory (NFI) of the Dominican Republic, which determined that the country's forest cover constituted 22.9 percent of its total land area. The purpose of the inventory was to determine the location, extent and structure of the country's forests. It included their delimitation, classification, species composition, dimensions, wood quality, diseases, trends and needs for forest management, with a primary focus on production (FAO, 1973).

In 2015, the Dominican Republic began to plan and implement the second NFI (NFI2), led by the Ministry of the Environment and Natural Resources (MARN) with technical support from the German Corporation for International Cooperation (GIZ) and in coordination with the Central American Commission for Environment and Development (CCAD), through the Regional Programme for Reducing Emissions from Deforestation and Forest Degradation in Central America and the Dominican Republic (REDD/CCAD-GIZ Regional Programme). During this process, which ended in May 2016, the pre-sampling stage (Phase I) was completed, which made it possible to assess logistics and access, institutional arrangements and the time required to establish the plots, and to gather field information to refine the calculation of the final sample size. The second phase of NFI2 was developed in 2018 and 2019 under the Dominican Republic Readiness Preparation Project, with support from the Forest Carbon Partnership Facility (FCPF) and the World Bank (Table 24.1).

24.2 RELEVANT TERMS AND DEFINITIONS

Table 24.2 presents the main definitions used to implement the second NFI, and their corresponding variables.

The reference level for the Reducing Emissions from Deforestation and Forest Degradation (REDD+) mechanism uses the following operational definition of forest:

> *Natural or planted ecosystem with biological diversity and enrichment of woody species, which produces goods and provides environmental and social services, whose minimum land area spans more than 0.81 ha [...] with a tree canopy cover exceeding 30 percent of that land area and trees or shrubs with the potential to reach a minimum height of 5 metres at maturity in situ and 3 metres for dry forest. Agroforestry systems that meet these criteria are included in this definition (MARN, 2019a, p. 11).*

The main objective of the second NFI was to determine the carbon stock, characteristics and state of the country's forest resources as a basis for guiding forest land management decisions and administration.

The field survey carried out during Phase I of the second NFI used the forest cover and land use map as a base (MARN, 2014). Later, for Phase II, the forest cover map developed in 2014 with RapidEye images and a 5-metre (m) resolution was used (MARN, 2015).

Finally, the processing phase of the second NFI used the latest forest cover survey of the Dominican Republic, carried out with 5-metre Planet imagery (MARN, forthcoming). Table 24.3 indicates the land areas obtained as a result of this last forest cover study. The forest types with the highest coverage are humid broadleaved forest (39.8 percent), dry forest (22.6 percent) and semi-humid broadleaved forest (15.2 percent) (see Table 24.3 and Figure 24.1).

TABLE 24.1

Historical overview of national forest inventories in the Dominican Republic

Inventory cycle	Implementation period	Scale	Sampling design	Number of sampling units
NFI1	1969–1972	National	Equal-sized square blocks, with 2 to 4 randomly distributed transects. Transects of 3 600 m^2 in pine forests (12 circles of 300 m^2, arranged in sequence 30 m apart) and 6 000 m^2 in broadleaved forests (30 circles of 200 m^2, arranged in sequence 20 m apart)	360
NFI2	2015–2018	National	Systematic stratified (7 strata and 0.1 ha in size)	404

Source: Prepared by the author.

TABLE 24.2

Summary of definitions used to implement the National Forest Inventory

Term	Definition	Variables and thresholds
Forest	A natural or disturbed ecosystem with a minimum area of 0.5 ha, with tree cover exceeding 40% of that area and trees and shrubs with the potential to reach a minimum height of 5 m at maturity.	Minimum area: 0.5 ha Canopy cover: 40% Tree height ≥ 5 m Minimum width: not defined
Other wooded land	Land not defined as forest spanning more than 0.5 ha, with a canopy cover of more than 40%, with shrub and tree species growing in areas of natural regeneration, with a height less than 5 m or capable of reaching these minimum limits *in situ*. In some cases, the ecological conditions, geological substrate and soil limit their development. It does not include land for primarily agricultural or urban use.	Minimum area: 0.5 ha Canopy cover: 40% Tree height ≥ 5 m Minimum width: not defined
Total volume (m^3)	Living trees with 2 cm DBH or greater, including bark.	Minimum diameter (DBH at 1.30 m): ≥ 2 cm Stump included Minimum diameter of stem end: zero Total height: from the base to the top of the crown
Biomass (kg)	Above-ground biomass: dry biomass (kg) of living trees with DBH of 2 cm or greater. Below-ground biomass: not measured Necromass: dry biomass of dead leaf litter material and lying cylindrical and semi-cylindrical dead wood from stems and branches with a minimum diameter of 10 cm and a minimum length of 1.5 cm. It does not include standing dead trees and stumps.	Above-ground biomass: minimum diameter (DBH at 1.30 m): 2 cm Below-ground biomass: not included Necromass: – stumps: not included – minimum diameter of lying dead wood: 2 cm Leaf litter: minimum sieved diameter not defined.

Source: **MARN (Ministry of the Environment and Natural Resources).** 2014. *Estudio de uso y cobertura del suelo 2012.* Santo Domingo.; **MARN.** 2021. *Inventario Nacional Forestal de la República Dominicana.* Santo Domingo.; **MARN & GIZ (German Corporation for International Cooperation).** 2014. *Manual de Campo del Inventario Nacional Forestal de la República Dominicana.* Santo Domingo, REDD/CCAD-GIZ Programme.

TABLE 24.3

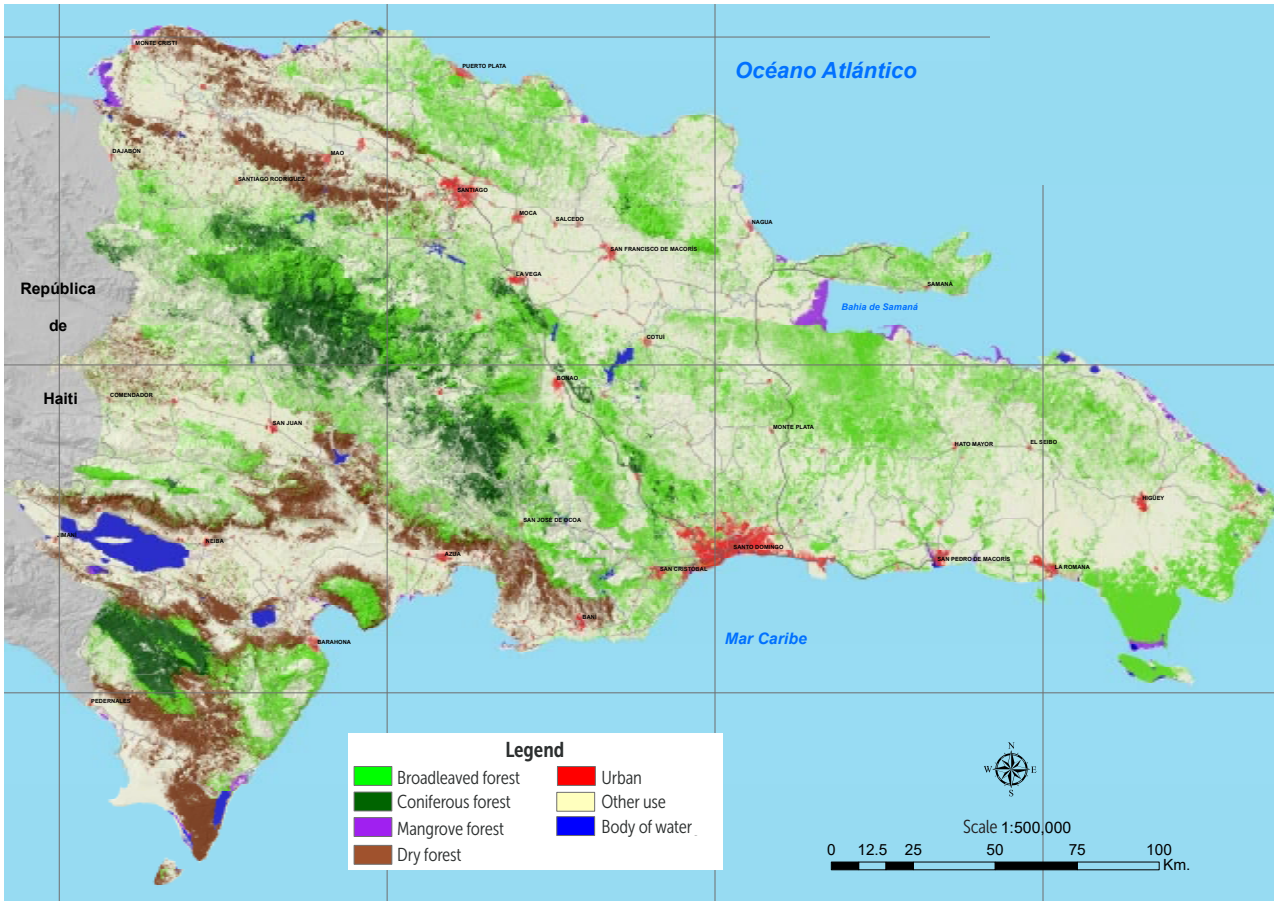
Land area with forest cover in the Dominican Republic as of 2020

Type of cover	Land area (1 000 ha)	Percentage (%)	
Dense coniferous forest	167.8	9.2%	13.8%
Sparse coniferous forest	83.3	4.6%	
Mangrove forest	27.0	1.5%	1.5%
Moist broadleaved forest	721.9	39.8%	62.1%
Broadleaved cloud forest	129.5	7.1%	
Semi-humid broadleaved forest	275.6	15.2%	
Dry forest	409.6	22.6%	22.6%
Total forests	**1 814.5**		**100%**
% of country			**37.7%**

Source: **MARN.** forthcoming. *Estudio de cobertura forestal de la República Dominicana utilizando imágenes Planet.* Santo Domingo.

FIGURE 24.1

Forest cover map of the Dominican Republic for 2019, with Planet images



The boundaries shown and the names and designations used on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any countries, territories, cities, areas, authorities, or delimitation of their frontiers or boundaries. Dotted lines on maps represent approximate boundaries for which there may not yet be full agreement.

Source: **MARN.** forthcoming. *Estudio de cobertura forestal de la República Dominicana utilizando imágenes Planet.* Santo Domingo.

TABLE 24.4

Characteristics of the sampling design of national forest inventories in the Dominican Republic

National Forest Inventory cycle	Total area (1 000 ha)	Number of sampling units			Total number of sampling units
		Forest	Other wooded land	Other land	
NFI 1	2 321	360	0	0	360
NFI 2	4 819	404	17	3	424

Source: Prepared by the author based on **FAO.** 1973. *Inventario y fomento de los recursos forestales – Inventario forestal.* Technical Report No. 3. Rome, FAO.; **MARN.** 2021. *Inventario Nacional Forestal de la República Dominicana.* Santo Domingo.

24.3 SAMPLING DESIGN

The first national forest inventory was conducted by FAO using the following process: a general working base was prepared from aerial photographs at a scale of 1:20 000 taken in 1966–67 and a national topographic map at a scale of 1:50 000 prepared by the Autonomous University of Santo Domingo in 1958–1960. In addition, various types of maps were used: maps of life zones, geological maps, land use maps, geomorphological maps, isohyets and topographic maps. With these resources, a pre-classification of land use was made from the photographs of forests and land under agricultural or other use. Forests were reported in five categories: mature pine forest, mixed mature forest, regenerating forest, broadleaved forest and dry broadleaved forest. As shown in Table 24.4, the design included 360 sampling units, in which the "block" was defined as the basic unit of homogeneous land cover, ranging from 100 hectares (ha) to 250 ha. Block sampling was done in 50 m transects and plots of 300 m² for conifers and 200 m² for broadleaved trees were randomly selected every 30 m and 20 m, respectively. The areas with homogeneous forest formations were called "units" and a set of contiguous units of the same forest type were called "compartments."

Regarding the NFI2 sampling design, a prestratification was defined to identify the existing forest types (dense coniferous, sparse coniferous; moist broadleaved, broadleaved cloud, semi-humid broadleaved; dry forest; mangrove). Each forest type had a corresponding stratum and systematic sampling was taken from each stratum, with a variable sampling intensity, so that the sampling error was less than 15 percent. The sampling unit used was a system of fixed plots of different dimensions according to the component to be measured, combining seven nested plots in the same site.

To increase the efficiency of the field survey in terms of logistics and travel time, the country was divided into six operational regions (OR): Northwest (OR I), Northeast (OR II), Southwest (OR III), South Central (OR IV), East (OR V) and Yaque del Norte (OR VI) (see Figure 24.3).

The first phase (pre-sampling) of the second NFI was conducted between January 2015 and May 2016. Twenty-two sampling units were established in each operational region, with the exception of RO VI (upper Yaque del Norte river basin pilot) with 19 units, totalling 129 sampling units that included seven forest types (Table 24.5).

The pre-sampling was used to assess the logistics and accessibility, institutional arrangements, and time required to establish the plots; in addition, field information was collected to refine the sample size calculation for Phase II of the second NFI. The pre-sampling also determined the number of plots required to achieve the pre-established sampling error (a maximum of 15 percent for each stratum), taking the main variable of interest (carbon dioxide [CO_2] stocks) as a reference, with a 90 percent statistical confidence level (Table 24.6).

Details of the plots assessed by each OR in the second NFI are shown in Table 24.7.

TABLE 24.5

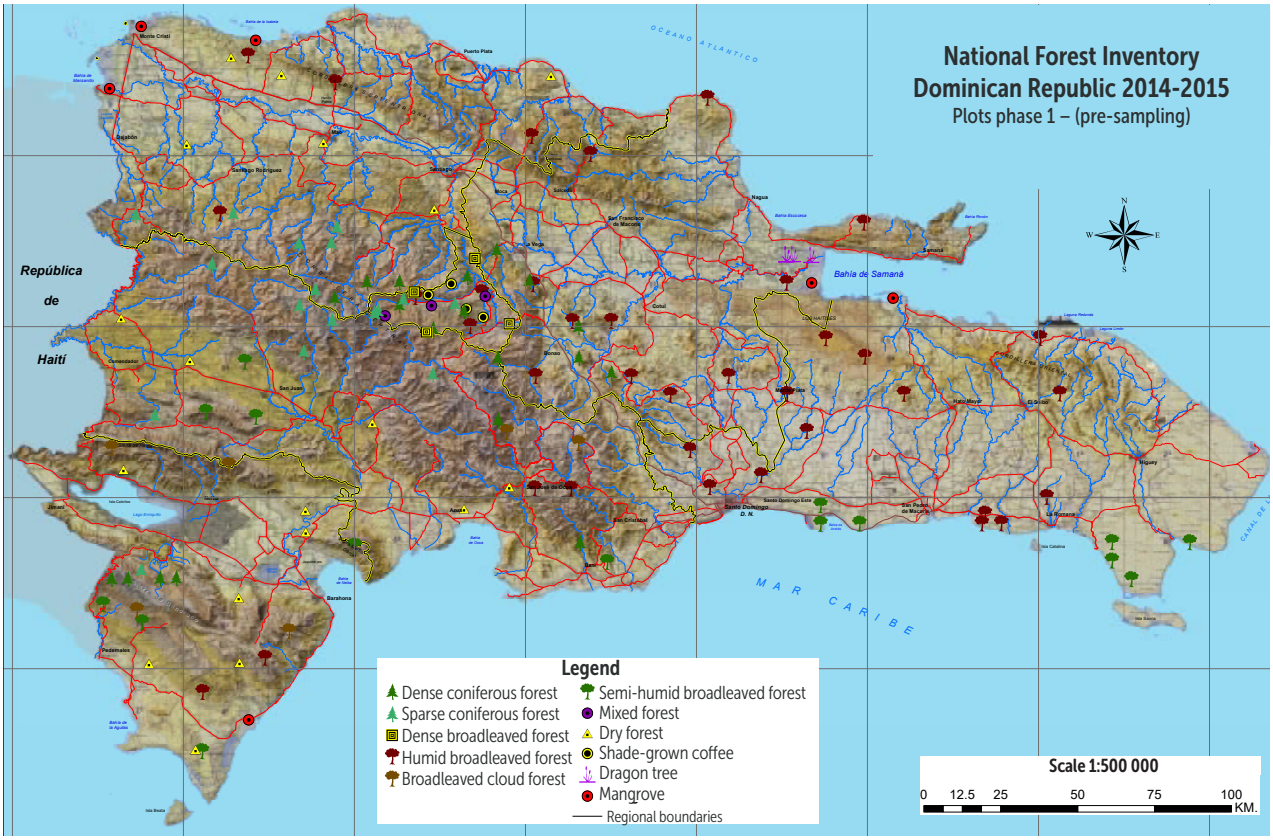
Sampling units per operational region of Phase I of the National Forest Inventory

Forest type	Operational region						
	I	II	III	IV	V	VI	Total
Dense coniferous forest	4	1	2	2	0	2	11
Sparse coniferous forest	5	2	1	3	0	7	18
Mangrove forest	3	5	1	0	1	0	10
Moist broadleaved forest	3	13	2	3	15	10	46
Broadleaved cloud forest	0	1	2	2	0	0	5
Semi-humid broadleaved forest	2	0	4	1	6	0	13
Dry forest	5	0	10	11	0	0	26
Total	**22**	**22**	**22**	**22**	**22**	**19**	**129**

Source: **MARN & GIZ.** 2016. *Memoria de cálculo y principales resultados del inventario nacional forestal de la República Dominicana. Primera aproximación con base en los resultados de la Fase I. Reporte Preliminar.* Santo Domingo, REDD/CCAD-GIZ Programme.

FIGURE 24.2

Distribution of primary sampling units in Phase I of the National Forest Inventory



The boundaries shown and the names and designations used on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any countries, territories, cities, areas, authorities, or delimitation of their frontiers or boundaries. Dotted lines on maps represent approximate boundaries for which there may not yet be full agreement.

Source: **MARN & GIZ.** 2016. *Memoria de cálculo y principales resultados del inventario nacional forestal de la República Dominicana. Primera aproximación con base en los resultados de la Fase I. Reporte Preliminar.* Santo Domingo, REDD/CCAD-GIZ Programme.

TABLE 24.6

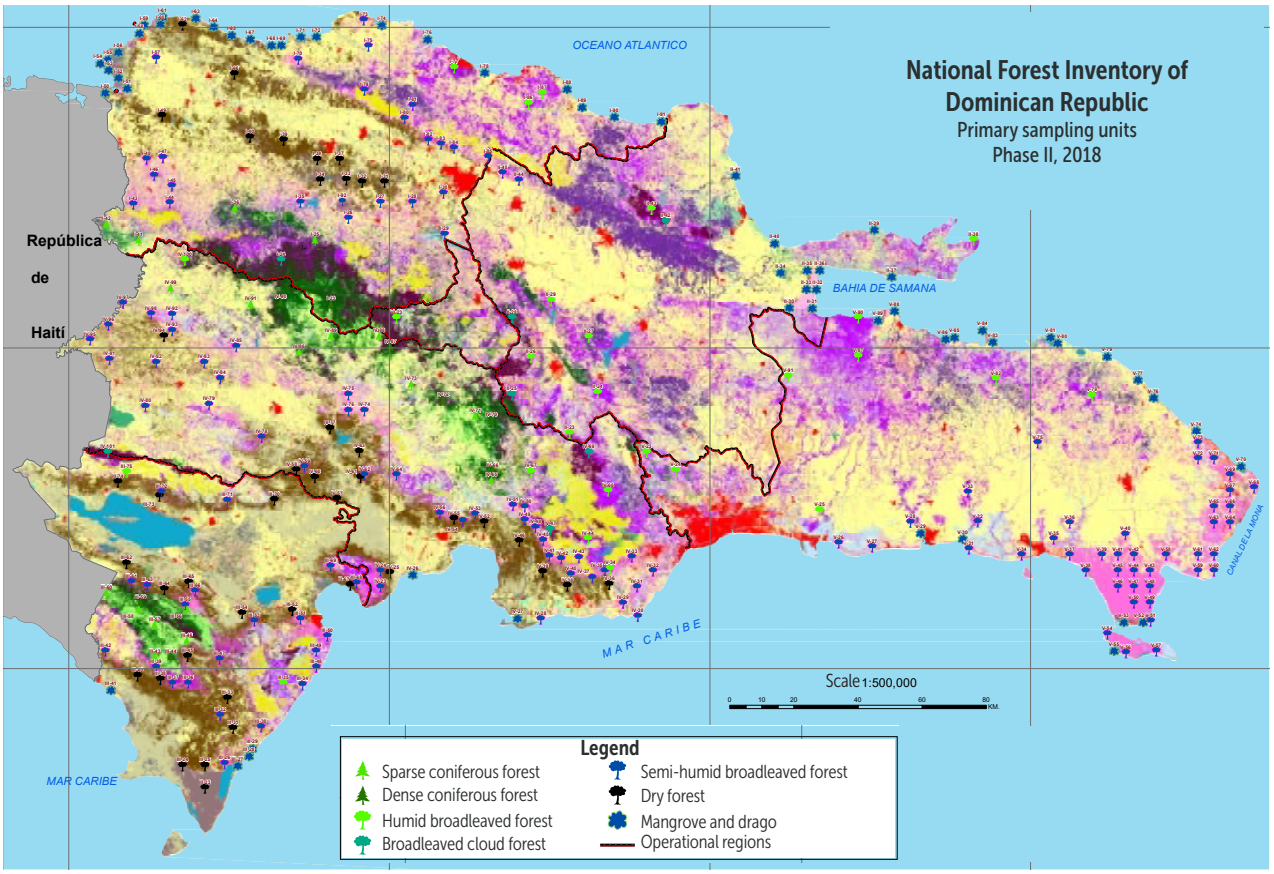
Sampling units scheduled for Phases I and II of the National Forest Inventory

Type of forest	Sampling error (%)	Sampling units Phase I	Sampling units proposed 90%	Sampling units to measure Phase II (90%)
Dense coniferous forest	15	11	19	8
Sparse coniferous forest	15	18	41	23
Mangrove forest	15	10	70	60
Moist broadleaved forest	15	46	76	30
Broadleaved cloud forest	15	5	11	6
Semi-humid broadleaved forest	15	13	136	123
Dry forest	15	26	71	45
Total		**129**	**424**	**295**

Source: **MARN.** 2019b. *Emission Reductions Program Document (ER-PD) of Dominican Republic.* Santo Domingo, World Bank and Forest Carbon Partnership Facility.

FIGURE 24.3

Location of sampling units in Phase II of the National Forest Inventory



The boundaries shown and the names and designations used on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any countries, territories, cities, areas, authorities, or delimitation of their frontiers or boundaries. Dotted lines on maps represent approximate boundaries for which there may not yet be full agreement.

Source: **MARN.** 2021. *Inventario Nacional Forestal de la República Dominicana.* Santo Domingo.

TABLE 24.7

Sampling units covered in Phase II of the National Forest Inventory per operational region

Stratum	Operational region						Total sampling units
	I	II	III	IV	V	VI	
Dense coniferous forest	5	1	4	7	0	2	19
Sparse coniferous forest	12	2	6	13	0	7	40
Mangrove forest	28	15	4	2	21	0	70
Moist broadleaved forest	10	19	3	10	23	11	76
Broadleaved cloud forest	1	4	2	4	0	0	11
Semi-humid broadleaved forest	24	2	16	36	39	0	117
Dry forest	17	0	25	29	0	0	71
Moist broadleaved shrubs	0	7	0	5	5	0	17
Non forest	0	0	1	2	0	0	3
Total	**97**	**50**	**61**	**108**	**88**	**20**	**424**

Source: **MARN.** 2019b. *Emission Reductions Program Document (ER-PD) of Dominican Republic.* Santo Domingo, World Bank and Forest Carbon Partnership Facility.

TABLE 24.8

Final sample size of the National Forest Inventory

Stratum	Phase I	Phase II	Total
Dense coniferous forest	11	8	19
Sparse coniferous forest	18	22	40
Mangrove forest	10	60	70
Moist broadleaved forest	46	30	76
Broadleaved cloud forest	5	6	11
Semi-humid broadleaved forest	13	104	117
Dry forest	26	45	71
Total	**129**	**275**	**404**

Source: **MARN.** 2021. *Inventario Nacional Forestal de la República Dominicana.* Santo Domingo.

In Phase II, 275 plots corresponding to forest cover were established. The consolidated information from Phases I and II of the second NFI yields the number of sampling units by forest type listed in Table 24.8, for a total of 404 plots.

The development of the second NFI was carried out in two phases of fieldwork, reaching a total sample of 404 plots in forest areas to estimate the variables of interest, as shown in Table 24.8.

The decrease in the number of plots in forest areas was due to the fact that the expected sampling error in the semi-humid broadleaved forest stratum was achieved with a lower number than originally foreseen; instead, 17 plots were measured in other forested areas and 3 plots in non-forested areas, thus completing the planned 424 plots.

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24.4 SAMPLING UNIT DESIGN

The type of sampling unit used in the second NFI corresponds to a system of nested plots of variable shapes and dimensions, depending on the specific tree or plant characteristics to be measured. The division of vegetation structures mainly relates to sizes (heights and diameters) and comprises the following seven categories:

- tree species with diameter at breast height (DBH) greater than or equal to 10 cm;
- tree species with DBH greater than or equal to 2 cm and less than 10 cm;
- regeneration of species (trees, shrubs, palms and arborescent ferns) with a height greater than or equal to 1.5 m and DBH smaller than 2 cm;
- herbaceous species;
- depth and weight of leaf litter on the forest floor;
- dead wood on the forest floor;
- soil organic carbon.

Table 24.9 and Figure 24.4 provide the correspondence between plot and subplot size and the carbon component to be assessed in the forest, as well as how to include certain variables of interest associated with forest dynamics.

As indicated in Table 24.9 and Figure 24.4, the primary sampling unit (PSU) is an individual rectangular plot, 20 m wide and 50 m long. The DBH of all dead and living standing trees with a DBH greater than or equal to or 10 cm located within the PSU must be measured. In addition, the location on a coordinate axis of each tree must be established and the stem quality and health status of all trees must be assessed. A subsample of 10 trees is taken to measure height and crown.

Four 0.5 m by 0.5 m square subplots, systematically distributed at each of the PSU vertices, are installed to assess the leaf litter. The regeneration is assessed by establishing three circular subplots with a 1 m radius, which are systematically located inside the PSU.

To assess biomass between 2 cm and 10 cm DBH, three 5 m by 10 m rectangular subplots are established, systematically located in the southwest corner, in the centre (east side) and in the northwest corner of the PSU; these are arranged in such a way that the 10 m are measured perpendicular to the axis of the PSU. Lying dead wood is measured via three linear transects with a length of 10 m, systematically at the ends and in the centre of the plot, along the longitudinal axis of the plot.

The diversity of shrubs, lianas, bamboo and ferns is measured in a subplot corresponding to a rectangular strip with an area of 25 m² (2.5 m by 10 m), arranged in the centre of the main plot and perpendicular to the longitudinal axis of the plot.

24.5 VOLUME, BIOMASS AND CARBON CALCULATION

This section presents the processing and calculations used during the second NFI for the volume, biomass and carbon variables, or the tree component with DBH greater than or equal to 2 cm.

Adjustment of height (total height): to obtain the remaining heights, the height equations were adjusted for each of the forest types under analysis. The following six models were tested in each case:

$$HT = a + b \times DBH$$

$$\frac{1}{HT} = a + \frac{b}{DBH}$$

$$Ln(HT) = a + b \times Ln(DBH) - 0.5$$

$$(HT - 1.3) - 0.4 = a + \frac{b}{DBH}$$

$$Ln(HT) = a + b \times Ln(DBH)$$

$$HT = a + b \times Ln(DBH)$$

Where:
a, b: constant
DBH: diameter at breast height
HT: total height

TABLE 24.9

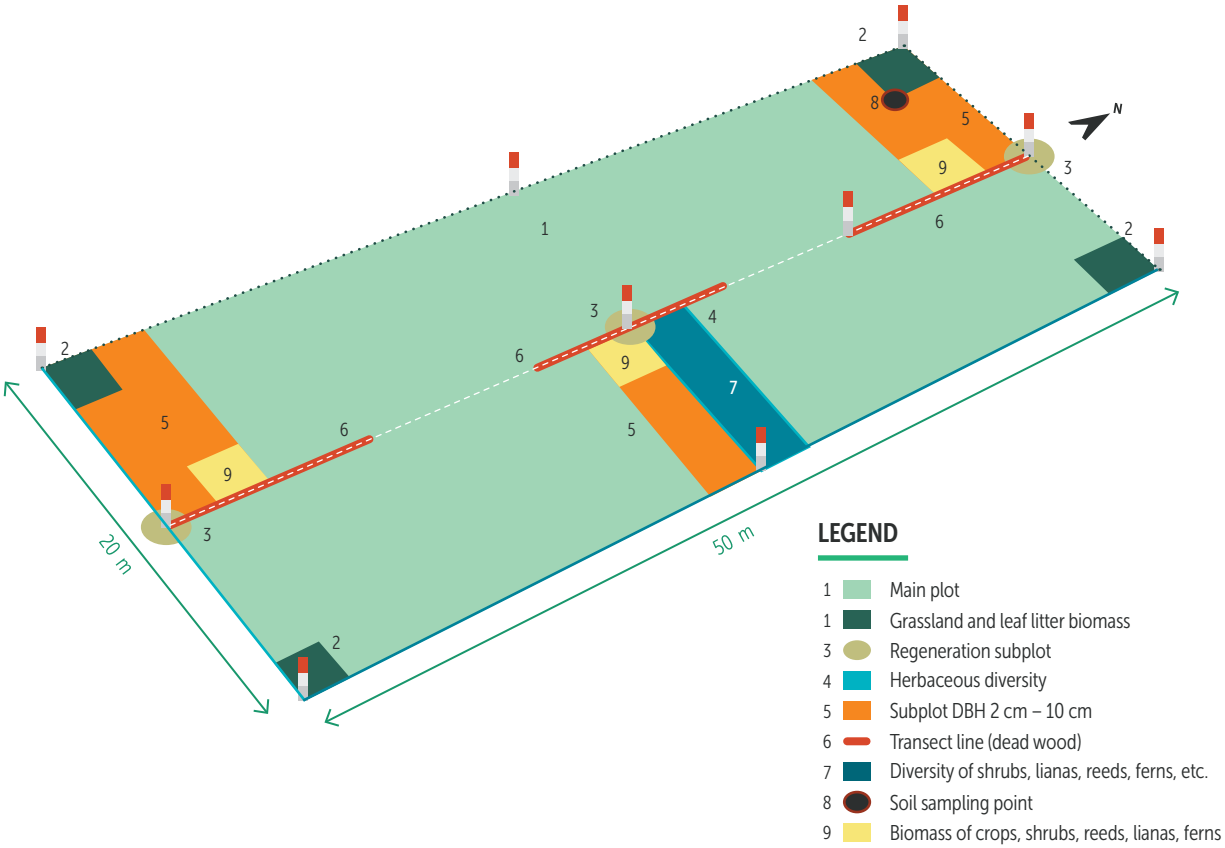
Vegetation to be assessed and the corresponding type of plot in the National Forest Inventory

N.º	Component	Type of plot
1	Above-ground biomass of trees greater than or equal to 10 cm diameter at breast height (DBH)	Main plot: rectangular, 20 m × 50 m (1 000 m^2)
2	Regeneration (trees smaller than 2 cm DBH)	Regeneration subplot: circular, 1 m radius (3.1416 m^2)
3	Biomass of trees greater than or equal to 2 cm DBH, but smaller than 10 cm DBH	Subplot: rectangular, 5 m × 10 m (50 m^2)
4	Dead wood biomass	Transect line: line measuring 10 m in length on which intersections with lying dead material are assessed
5	Grassland and leaf litter biomass	Subplot: 0.5 m × 0.5 m (0.25 m^2)
6	Ground biomass	Ground sampling point
7	Herbaceous diversity	Herbaceous subplot: square, 1 m^2
8	Diversity of shrubs, lianas, reeds, ferns and other plants	Shrubs plot: rectangular, 2.5 m × 10 m (25 m^2)

Source: **MARN.** 2021. *Inventario Nacional Forestal de la República Dominicana.* Santo Domingo.

FIGURE 24.4

Plot design to collect National Forest Inventory data



Source: **MARN & GIZ (German Corporation for International Cooperation).** 2014. *Manual de Campo del Inventario Nacional Forestal de la República Dominicana.* Santo Domingo, REDD/CCAD-GIZ Programme.

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Table 24.10 shows the equations used for volume, biomass and carbon calculations.

TABLE 24.10

Equations used for volume, biomass and carbon calculations

Variable	Equation	Reference
Total volume (m^3)	$V = BA \times HT \times 0.5$ Where: *V:* total volume (m^3) *BA:* basal area *HT:* total height	Form factor of 0.5
Biomass (kg)	Broadleaved species DBH ≥ 5 cm	Chave *et al.* (2014)
	$B = 0.0673 \times (SG \times DBH^2 \times HT)^{0.976}$	The specific gravity (SG) was obtained from the literature, whose main source is Chave *et al.* (2006). First, the value of the specific species (genus/species) is sought; if not found, the value for the genus or family level is sought.
	Broadleaved species DBH ≥ 2.0 cm and ≤ 4.99 cm $B = EXP\,(-0.37673 + 2.30119 \times LnDBH + 0.30297 \times LnHT)$	Arreaga (2002)
	Rhizophora mangle species DBH ≥ 5.0 cm $B = EXP\,(-1.91 + 2.59 \times LnDBH)$	Yepes *et al.* (2015)
	Coniferous species DBH ≥ 2.0 cm $B = EXP\,(-1.17 + 2.119 \times LnDBH)$	Márquez (2000)
	Leaf litter $\%DW = \frac{DW}{FW}$ $B = \%DW \times GW$	
	Where: *B*: biomass *DBH*: diameter at breast height *SG:* specific gravity *HT*: total height *FW:* fresh weight *DW:* dry weight *GW*: green weight	
Carbon (t)	Leaf litter: $C = B \times FC_{(lab)}$	
	Above-ground: $C_A = B \times 0.5$	IPCC (2006)
	Roots: $C_{roots} = C_A \times 0.2$	IPCC (2006)
	$CO_2\ fixed = C \times (\frac{44}{12})$	
	Where: *B*: biomass *C*: carbon C_A: above-ground carbon C_{roots}: roots carbon $CF_{(lab)}$: carbon fraction obtained in laboratory	

Source: **Arreaga, W.** 2002. *Almacenamiento del carbono en bosques con manejo forestal sostenible en la Reserva de Biosfera Maya, Petén, Guatemala.* Turrialba, Costa Rica, Tropical Agricultural Research and Higher Education Center. Thesis.; **IPCC (Intergovernmental Panel on Climate Change).** 2006. Chapter 2: Generic Methodologies Applicable to Multiple Land-use Categories. In: H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, & K. Tanabe, eds. *2006 IPCC Guidelines for national greenhouse gas inventories. Volume 4: Agriculture, forestry and other land use.* Hayama, Japan, Institute for Global Environmental Strategies.; **Márquez, L.**, ed. 2000. *Elementos técnicos para inventarios de carbono en uso del suelo.* Guatemala City, Fundación Solar.; **Yepes, A., Zapata, M., Bolivar, J., Monsalve, A., Espinosa, S., Sierra-Correa, P. & Sierra, A.** 2015. Ecuaciones alométricas de biomasa aérea para la estimación de los contenidos de carbono en manglares del Caribe Colombiano. *Revista de Biología Tropical*, 64(2): 913–926.;

24.6 MAIN RESULTS

Considering trees with DBH greater than or equal to 10 cm and when analysing all the defined forest types, the following estimates are obtained for the forests of the Dominican Republic: an average of 396 trees per hectare; an average DBH of 18.2 cm (± 4.5 percent); an average total height of 10.0 m (± 2.9 percent); an average basal area of 13.4 m²/ha (± 14.3 percent); and an average volume of 91.6 m³/ha (± 17.6 percent) (see Table 24.11).

Table 24.12 shows the carbon content by component and forest type that was obtained from the second NFI. Soil carbon accounts for 78.6 percent of the carbon stock, while the overall average, including soil, is 980.4 tonnes per hectare (t/ha). Trees with DBH greater than 10 cm have 124.5 t/ha (12.7%) on average.

The total carbon dioxide (CO_2) stock estimated by the second NFI of the Dominican Republic amounts to 1 833.3 million tonnes; this estimate has an associated sampling error of 4.3 percent. In terms of the uncertainty associated with the estimates by forest type, the maximum sampling error corresponds to 17.9 percent in the moist broadleaved forest, while the minimum sampling error corresponds to 5.6 percent for the semi-humid broadleaved forest stratum. The forest type with the highest total CO_2 stock is the moist broadleaved forest, with 0.65 gigatons (35.6 percent of the total), followed by the dry forest with 0.45 gigatons (24.7 percent of the total) (see Table 24.13).

With regard to each of the CO_2 sinks assessed in the second NFI, if soil CO_2 is not considered, the largest CO_2 stocks are provided by trees greater than or equal to 10 cm DBH, which account for 58.4 percent of total CO_2, followed by roots (19.4 percent) and dead wood (7 percent). When soil (at a depth of 30 cm) is included in the analysis as a CO_2 sink, this component alone accounts for 78.6 percent of the total CO_2, followed by trees greater than or equal to 10 cm DBH (12.5 percent).

According to the biodiversity indices calculated with the information from the second NFI and considering trees greater than or equal to 2 cm DBH, the semi-humid broadleaved forest and humid broadleaved forest strata have the highest species diversity, with 235 and 230 different species, respectively. The next most diverse stratum is the dry forest, with 177 different species.

Regarding forest regeneration in the Dominican Republic, the average density is 28 227 plants/ha, with a sampling error of 18.5 percent. The highest level of regeneration was found in the mangrove forest, moist broadleaved forest and dry forest strata, with 52 233 plants/ha, 35 098 plants/ha and 32 623 plants/ha, respectively. By contrast, dense coniferous forest and sparse coniferous forest showed the lowest level of regeneration, with only

TABLE 24.11

Dasometric results for all forest types

Forest type	Area (1 000 ha)	Number (trees/ha)	Diameter at breast height (cm)	Total height (m)	Basal area (m^2/ha)	Volume (m^3/ha)
Dense coniferous forest	167.8	513	20.6	12.8	18.2	142.9
Sparse coniferous forest	83.3	322	21.0	13.2	12.6	100.3
Mangrove stands	37.0	454	16.6	10.0	13.3	97.1
Moist broadleaved forest	721.9	414	19.8	10.8	16.7	119.0
Broadleaved cloud forest	129.5	479	19.5	10.9	19.8	154.5
Semi-humid broadleaved forest	275.6	357	16.5	8.6	9.5	48.5
Dry forest	409.6	328	14.7	7.5	6.6	29.1
General average		**396**	**18.2**	**10.0**	**13.4**	**91.6**

Source: Adapted from **MARN.** 2021. *Inventario Nacional Forestal de la República Dominicana.* Santo Domingo.

3 797 plants/ha and 5 942 plants/ha, respectively. The semi-humid broadleaved forest and moist broadleaved forest strata have the highest diversity of regenerating species (135 and 121 distinct species, respectively), while in the mangrove forest and dense coniferous forest strata, regeneration biodiversity is low (11 and 19 different species, respectively). Considering all strata together, an estimated 238 different tree species are undergoing regeneration in the forests of the Dominican Republic.

Given the different levels of information available, the diversity of variables assessed and the incorporation of the various structural components of the forest into the characterization of forest ecosystems, the development of the second NFI has made it possible to quantify and characterize the existing forest resources in the country. This information is crucial for establishing the baseline for the implementation of measurement, reporting and verification (MRV) within the framework of the National REDD+ Strategy. Likewise, the information collected, and the multiple possible combinations of analysis that can be carried out using these data, are key decision-making elements for sustainable forest management in the Dominican Republic.

TABLE 24.12

Carbon dioxide stock in the National Forest Inventory strata

Forest type	Carbon dioxide (t/ha)							
	Trees ≥ 10 cm	Trees 2 cm – 10 cm	Roots	Leaf litter	Dead wood	Total without soil	Soil	Total with soil
Dense coniferous forest	190.1	22.8	57.5	9.6	9.6	289.4	461.2	750.7
Sparse coniferous forest	130.8	16.3	39.7	5.2	12.2	204.3	595.0	799.3
Mangrove forest	155.2	35.4	51.5	0.9	10.1	253.1	1 119.1	1 372.2
Moist broadleaved forest	155.8	20.3	47.6	3.0	12.8	239.5	665.9	905.4
Broadleaved cloud forest	210.3	25.4	63.6	1.4	66.9	367.6	637.0	1 004.6
Semi-humid broadleaved forest	72.2	34.4	28.8	2.9	7.6	145.9	987.5	1 133.4
Dry forest	47.5	44.1	24.7	2.1	10.2	128.6	978.3	1 106.9
General Average	124.5	28.5	41.3	3.3	14.9	212.6	767.8	980.4
	12.7%	2.9%	4.2%	0.3%	1.5%	21.4%	78.6%	100%

Source: **MARN.** 2021. *Inventario Nacional Forestal de la República Dominicana.* Santo Domingo.

TABLE 24.13

Total carbon dioxide stock by forest type and component

Forest type	Carbon dioxide, in million tonnes						
	Trees ≥ 10 cm	Trees 2 cm – 10 cm	Roots	Leaf litter	Dead wood	Soil	Total
Dense coniferous forest	31.8	3.8	9.6	1.6	1.6	77.3	125.7
Sparse coniferous forest	10.9	1.4	3.3	0.4	1.0	49.6	66.6
Mangrove forest	4.2	1.0	1.4	0.02	0.3	30.2	37.0
Moist broadleaved forest	112.5	14.7	34.3	2.2	9.2	480.7	653.5
Broadleaved cloud forest	27.2	3.3	8.2	0.2	8.7	82.5	130.1
Semi-humid broadleaved forest	23.4	11.1	9.3	0.9	2.5	319.6	366.8
Dry forest	19.5	18.1	10.1	0.9	4.2	400.7	453.4
General Average	229.5	53.3	76.3	6.2	27.4	1 440.6	1 833.3
	12.5%	2.9%	4.2%	0.3%	1.5%	78.6%	100%

Source: **MARN.** 2021. *Inventario Nacional Forestal de la República Dominicana.* Santo Domingo.

24.7 SUPERVISION AND QUALITY CONTROL

The accuracy of a forest inventory is indicated by the total error, which is the difference between a sample estimate and the true population value; it includes sampling errors (or random errors) and biases (or systematic errors) that may originate from the sampling procedure or from measurement errors (Prodan *et al.*, 1997; Ríos *et al.*, 2000). The National Environmental Authority (Autoridad Nacional Del Ambiente – ANAM, according to its acronym in Spanish) and the International Tropical Timber Organization (ITTO) (2002) point out that inventory quality control is a continuous process that starts with the execution of the inventory.

The implementation of the second NFI was outsourced to consulting companies. In Phase I, national experts were hired for field data collection. In Phase II, the Sud-Austral Consulting–Centro Regional de Estudios y Servicios (CRESER) consortium was hired, following the World Bank protocols for international tenders. Regarding the monitoring and quality control of the second NFI, the measures taken by the Sud Austral-CRESER consortium consisted of:

- establishment and operation of an office of the consulting firm in the Dominican Republic, which would act as a permanent link between the consortium and MARN;
- formation of field teams with staff previously trained in the implementation of sampling units;
- training activities prior to the fieldwork;
- regular and systematic supervision of the crews during the fieldwork;
- review of the information collected in the field to verify accuracy;
- second review of the forms in digital format, prior to entering them into the database;
- permanent coordination with the MARN staff who were responsible for monitoring the activities.

In general, the quality control of an NFI is conducted by surveying selected plots (called control plots) in order to detect and analyse deviations that may occur in the data collection. The quality assessment of the field data of the second NFI was conducted by the MARN Forest Monitoring Unit (FMU), which selected, located and remeasured at least 10 percent of the sampling units established by each of the field crews, while ensuring an equitable distribution among the different strata and the various field crews.

In keeping with the above, the FMU developed a quality control protocol for the second NFI, which was communicated to the field crews prior to the start of the fieldwork. The NFI supervision team checked the work of the field crews at regular intervals, supporting and monitoring them, verifying the assimilation of the knowledge received during the training, and ensuring that the procedures and definitions were understood and applied in the field.

The introduction of quality control crews contributes to the success of the inventories in two ways:

- first, in the training of field crew staff;
- second, because the data collected by the quality control crew will be used to know the frequency and magnitude of errors and biases committed by the field crews, which must be reported immediately in order to take corrective measures.

Regarding the qualification of the fieldwork, it was decided to remeasure all the plots under the responsibility of a given field crew when there are differences that exceed the required ranges in more than 10 percent of the plots controlled by that crew, or when there are measurements that demonstrate bias or flawed judgement.

24.8 GENDER APPROACH

An evaluation was conducted regarding the participation of men and women in all phases of the second NFI, which includes training, field crews, community guides, technical assistance, technical supervision and editing of the final report. The results showed that 485 people participated, of which 18 percent were women and 82 percent were men. The participation of women was prominent in composition of the field crews, representing 25 percent, and in editing the final report, representing 66 percent. The participation of men was very high in the roles of community guides, park rangers and forest rangers, representing over 90 percent.

24.9 FUTURE PROSPECTS

In order to measure the dynamics or changes in forest attributes, permanent forest monitoring plots will be established for all forest types in the country. In addition, assessments of areas of change by remote sensing (activity data) are planned to be conducted every two years, using Landsat images for land use mapping. To assess the dynamics of deforestation and forest degradation, the method of visual interpretation of sampling points will be used, following the good practises and procedures of Olofsson *et al.* (2014).

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NEXT CHAPTER

SURINAME

Chapter 25

SURINAME

TOWARDS A NATIONAL FOREST INVENTORY IN SURINAME

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25.1 HISTORICAL OVERVIEW

National forest assessments in Suriname were first carried out in the 1970s in collaboration with the Food and Agriculture Organization of the United Nations (FAO) to gain a better understanding of the commercial timber volumes. More recently, one of the steps to collect national data on forest carbon stocks, as part of the country's preparation to be included in the REDD+ (Reducing emissions from deforestation and forest degradation) mechanism of the United Nations Framework Convention on Climate Change (UNFCCC), was a Forest Carbon Assessment and Monitoring Project carried out from 2010 to 2012 (Crabbe *et al.*, 2012). The field information was derived from 12 locations in three main forest types: high dryland forest, marsh forest and low xerophytic forest. At each location, a transect was established, consisting of three permanent plots of 0.5 hectares (ha) measuring 50 metres (m) by 100 m, one kilometre (km) apart from each other. Above-ground biomass (AGB) and standing dead wood data were recorded in these plots. At a distance of 10 m from each corner of these plots, quadrats of 3 m by 3 m were laid out where the understorey, coarse and fine dead wood branches were harvested and weighed. Additionally, soil samples were taken to a depth of 1 m to assess the soil organic carbon stock.

In 2014, in collaboration with the Austrian Natural Resources and International Cooperation Agency, a national monitoring design was set up based on a three-stage sampling approach. Fieldwork was carried out in 31 locations following a 20 km by 20 km grid, establishing 8 ha by 0.2 ha cross clusters. Due to technical problems, this inventory was never finalised; however, the recorded data together with additional research databases served as the basis for current carbon estimates (SBB *et al.*, 2017).

Next, in 2016, a workshop was organized in Suriname aiming to obtain an overview from National Forest Inventories (NFIs) from other countries in the region. The habitat method used in French Guiana was pointed out as a possible approach for Suriname, especially because an initial regional stratification had been defined for Suriname.

Finally, in 2019 an NFI was designed using the base of a 20 km by 20 km grid as a starting point, combined with maps aiming to obtain a reliable result not only within the national scale, but also for a specific relevant forest type: the mangrove forest. In the mangrove forest, the design was densified to 2 km by 2 km. As a result, 11 clusters of 4 ha by 0.2 ha sampling units were set up (Table 25.1 and Figure 25.1). This was a multipurpose inventory, which included, among others, collecting plant material (herbarium), camera traps, soil sampling and bird spotting (SBB *et al.*, 2019).

In 2022, six additional clusters with the same design will be established in the mangrove forest.

TABLE 25.1

Historical description of the inventories implemented towards a National Forest Inventory

Inventory cycle	Execution period	Level	Sampling design	Number of sampling units
Pilot NFI	2014	National	20 km × 20 km grid	31
National mangrove forest inventory	2018–2019	National (mangrove forests)	20 km × 20 km grid combined with mangrove forest type maps based on satellite images	11 clusters of 4 ha × 0.2 ha

Source: Prepared by the authors.

FIGURE 25.1

National mangrove forest inventory sampling design

Source: **SBB (Foundation for Forest Management and Production Control), BBS (National Herbarium of Suriname), CELOS (Center for Agricultural Research in Suriname), NB (National Conservation Division) & NZCS (National Zoological Collection Suriname).** 2019. *GCCA+ Suriname Adaptation Project: Setting up a mangrove biodiversity monitoring system – Final Report.*

25.2 TERMS AND DEFINITIONS

The definitions for the NFI (SBB *et al.*, 2019) are the same as the definitions used for the Satellite Land Monitoring System and for the reports prepared within the REDD+ framework (such as Suriname's first and second forest reference emission level submissions to UNFCCC). These definitions were used for the Forest Resources Assessments (FRA) from 2015 and 2020. They have a technical character and differ from the administrative-based definitions in the Forest Management Act (Suriname, 1992) (see Table 25.2).

TABLE 25.2

Summary of definitions used to implement the National Forest Inventory

Term	Definition	Variables and thresholds
Forest	Land covered primarily by trees, but also often containing shrubs, palms, bamboo, herbs, grass and climbers, with a minimum tree crown cover of 30% (or equivalent stocking level), with the potential to reach a minimum canopy height at maturity *in situ* of 5 metres, and a minimum area of 1.0 hectare. The forest definition in Suriname excludes crown cover from trees planted for agricultural purposes (including palm trees such as coconut, oil palm etc.) and tree cover in areas that are predominantly under urban or agricultural use.	Area: 1 ha Height: 5 m Tree crown cover: 30%
Other wooded land	No country-based definition	
Other land	No country-based definition	
Volume	All tree species with a diameter at breast height (DBH) above 5 cm, stem volume up to the commercial height	DBH (at 1.3 m) > 5 cm
Biomass	Above-ground biomass (AGB): dry biomass of all trees (including palm trees and lianas), with a diameter at breast height (DBH) above 5 cm	AGB: DBH (at 1.3 m) > 5 cm
	Dead organic material (DOM): all standing and lying dead trees with a diameter of 10 cm or more	DOM: diameter > 10 cm

Source: **SBB.** 2017. *NFMS Roadmap: Status and plans for Suriname's National Forest Monitoring System.* Paramaribo.

TABLE 25.3

Characteristics of the sampling design

Region	Total area (1 000 hectares)	Number of sampling units			Total number of sampling units
		Forest	Other wooded land	Other land	
Pilot NFI (other forest)	16 290	31	0	0	31
National mangrove forest inventory	90	11	0	0	0
Total	16 380	42	0	0	42

Source: Prepared by the authors.

25.3 SAMPLING DESIGN

A sampling design based on a 20 km by 20 km grid was established for the whole country. This was applied in the pilot NFI. For the NFI clusters established in the mangrove forest, the distribution of the plots was made based on a combination of this grid and remote sensing-based maps of mangrove forest types, aiming to obtain an equally distributed network of plots within the often-inaccessible mangrove forest (Table 25.3).

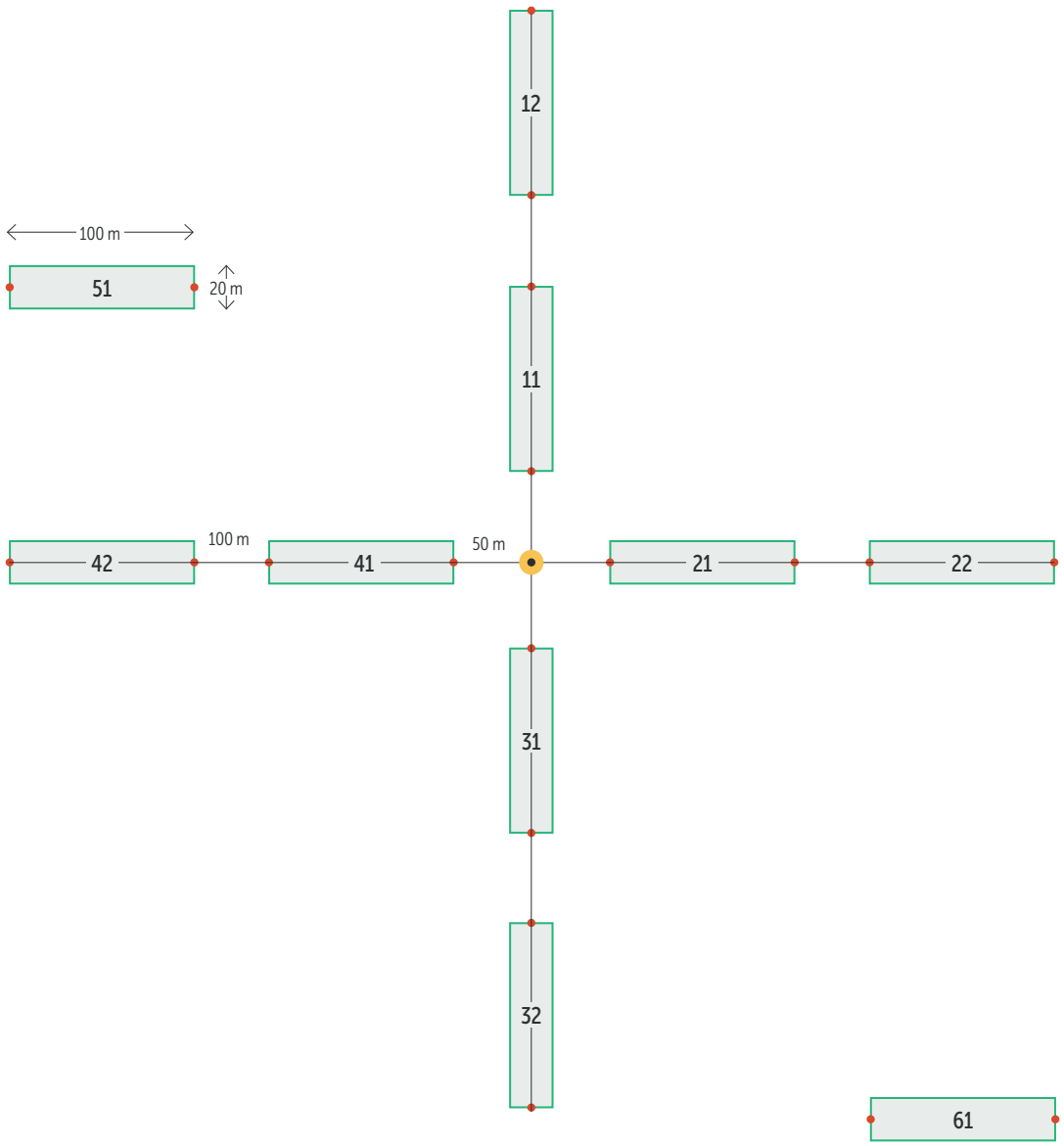
25.4 SAMPLING UNIT DESIGN

25.4.1. PILOT NATIONAL FOREST INVENTORY

Each cluster or sampling unit (SU) was composed of four principal sampling plots (PSP) in a north-south orientation and four PSPs oriented east-west (Figure 25.2). The two lines of PSPs formed a cross-shaped configuration. The PSPs were further subdivided into twenty subplots called main assessment plots, measuring 10 m by 10 m (Figure 25.4).

FIGURE 25.2

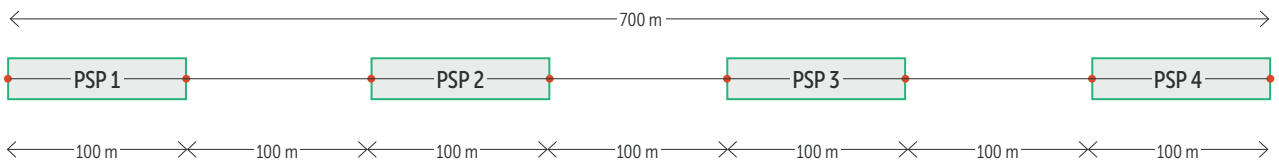
Cluster design for the pilot National Forest Inventory



Source: **SBB.** 2017. *NFMS Roadmap: Status and plans for Suriname's National Forest Monitoring System.* Paramaribo.

FIGURE 25.3

Cluster or sampling unit designed for the pilot National Forest Inventory and mangrove forest inventory



Note: PSP: principal sampling plot.
Source: **SBB, BBS, CELOS, NB (National Conservation Division) & NZCS.** 2019. *GCCA+ Suriname Adaptation Project: Setting up a mangrove biodiversity monitoring system – Final Report.*

For all trees with a diameter at breast height (DBH) greater than or equal to 20 centimetres (cm), the following parameters were measured: species, diameter, total height, commercial height, decay status and the stem quality.

Additionally, trees with a DBH greater than or equal to 10 cm and those with a DBH of 5 cm or more were assessed, respectively, in four and two MAPs measuring 10 m by 10 m in each PSP. For smaller tree species, diameter and total height were recorded. In the whole PSP, all standing dead trees with a DBH of 10 cm or more were measured, recording the species, DBH, height and degree of decay. Two nested plots of 5 m by 5 m were established where regeneration with a DBH less than 5 cm was counted, and the diameter and length of lying dead wood with a diameter greater than 10 cm was recorded.

Within the different (sub)plots, the following data were collected:

- Full PSP: diameter and species name of all trees with DBH greater than 20 cm and standing dead trees with DBH greater than or equal to 10 cm;
- MAPs 17 and 4: diameter and species name of all trees, lianas with DBH greater than 10 cm;
- MAPs 18 and 3: all trees with DBH greater than 5 cm; in the 5 m by 5 m quadrat, regeneration was counted per species and lying dead wood was measured.

25.4.2. MANGROVE FOREST INVENTORY

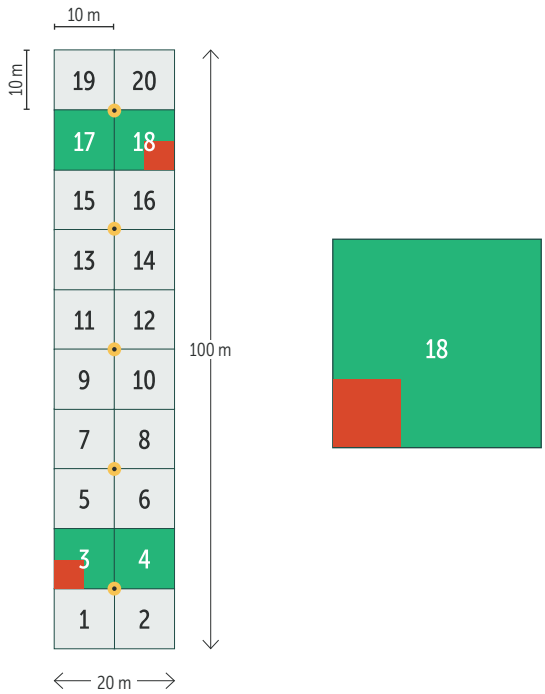
Due to the east-west alignment of the mangrove forest along the coastline, the plots were only established in a linear configuration. Each cluster or SU was composed of four PSPs (Figure 25.3). The PSPs were subdivided into twenty MAPs of 10 m by 10 m, as in the pilot NFI (Figure 25.4).

The following data were collected for the mangrove forest inventory (see Figure 25.4):

- Full PSP: diameter, species name and total height of all trees (living and dead) with a DBH greater than 10 cm;
- MAPs 18 and 3: all trees with DBH greater than 5 cm; in the 5 m by 5 m quadrat, regeneration was counted per species, and the diameter and length of lying dead wood with diameter greater than 10 cm was recorded.

FIGURE 25.4

Principal sampling plot for pilot National Forest Inventory and mangrove forest inventory



Source: **SBB.** 2017. *NFMS Roadmap: Status and plans for Suriname's National Forest Monitoring System*. Paramaribo.

25.5 CALCULATION OF AREA, VOLUME AND BIOMASS

Because the NFI has not been completed, the available data have not been used to calculate the area. Instead, the country's estimations of forest cover and forest cover loss are based on satellite images. For volume, the formulas compiled by SBB *et al.* (2017) were considered. For biomass, an assessment was recently conducted by Wortel and Sewdien (2020) comparing the data of 31 felled trees with the different pantropical allometric equations. During this study, it was found that there were two different approaches in Chave *et al.* (2014) to estimate biomass. The best approach included height measurement and, although the second one does not include height, it considers an environmental parameter, wood density and DBH. Because height measurements are very labour-intensive to acquire in the tropical forest of Suriname, Chave *et al.* (2014) equations without height measurements were used. All calculations were done using R core software.

TABLE 25.4

Equations used for volume and biomass/carbon calculations

Variable	Equation	Reference
Total volume (m^3)	$0.75 \times (DBH/200)^2 \times H \times PI$ Where: *DBH:* diameter at breast height *H:* height	SBB *et al.* (2017)
Biomass (kg)	$AGB = exp\ (-1.803 - 0.976E + 0.976ln(\rho) + 2.673 \times ln(D) - 0.0299 \times (ln(D)^2)$ Donde: *AGB:* above-ground biomass *ρ:* wood density *D:* diameter at breast height	Chave *et al.* (2014)

Source: **Chave, J., Réjou-Méchain, M., Búrquez, A., Chidumayo, E., Colgan, M.S., Delitti, W.B.C., Duque, A.**, et al. 2014. Improved allometric models to estimate the aboveground biomass of tropical trees. *Global Change Biology*, 20(10): 3177–3190.; **SBB.** 2017. *NFMS Roadmap: Status and plans for Suriname's National Forest Monitoring System.* Paramaribo.

TABLE 25.5

Best available results from recent assessments

Variable	Description	Result	Reference
Area	Forest area (1 000 hectares)	15 185	Based on SBB (2021)
Volume	n/a	n/a	n/a
Biomass	Above-ground biomass (tonnes/hectare)	343.58 to 408.44	Based on Government of Suriname (2021)
Carbon	Above-ground carbon (tonnes/hectare)	171.79 to 204.22	Based on Government of Suriname (2021)

Source: **SBB.** 2021. *Forest cover monitoring in Suriname using remote sensing techniques*. Paramaribo.; **Government of Suriname.** 2021. *Forest Reference Emission Level for Suriname's REDD+ Programme.* Paramaribo.

25.6 RESULTS OF THE MOST RECENT NATIONAL FOREST INVENTORY

In January 2021, Suriname provided a second submission of its Forest Reference Emission Level (FREL) to the UNFCCC. In the FREL report, all data from SBB *et al.* (2017), including the pilot NFI, Forest Carbon Assessment and Monitoring Project, and relevant research datasets, were recalculated using the Chave *et al.* (2014) allometric equations. This has resulted in lower biomass values than the original values using Chave *et al.* (2005). In addition, the recent measurements within the mangrove forest were considered for the FREL estimations. However, the volume has not yet been calculated based on these data (Table 25.5).

25.7 IMPLEMENTATION AND QUALITY CONTROL

Within the best estimates assessment (SBB *et al.*, 2017), a quality control procedure using InfoStat statistical software was implemented on the data set, including following steps:

- unification and standardization of all data, including the unification of all scientific names for the tree species that were identified using their local tree names;
- detection of outliers using the minimum and maximum function;
- identification of outliers by tree species.

An identical approach was applied to the national mangrove forest inventory data set; for this analysis, R Studio software was used.

25.8 OTHER RELEVANT VARIABLES COLLECTED

The following relevant variables were monitored in the mangrove forest inventory:

- Botanical plant collection: only fertile (flower or fruiting) plants were collected, for identification and validation of the occurring species. Plants were pressed in the field or in the processing room of the National Herbarium of Suriname.
- Bird diversity assessment: birds were observed and counted using the line transect method within mangrove monitoring plots. During this assessment, all birds seen and heard on all sides of the transect line were counted. Using these data, together with the frequency of their occurrence, diet and total numbers, a bird classification table was then developed.
- Mammal diversity: a total of four camera traps (Reconyx Ultrafire) were used to assess the large mammal biodiversity in the mangrove plots established along the coastline of Suriname. Camera traps were placed at seemingly appropriate places determined by existing tracks, scat or water bodies. These traps were placed in trees at a height of approximately 40 cm and secured with a quick fastener and a Python cable lock.
- Soil monitoring: the soil sampling and soil description took place in two PSPs. The mangrove soils were sampled at depths of 0 cm to 15 cm, 15 cm to 30 cm, 30 cm to 50 cm, and 50 cm to 100 cm for carbon concentration. For the bulk density, soil samples were collected at the midpoint of each sample depth used for the carbon concentration: 5 cm to 10 cm, 20 cm to 25 cm, 38 cm to 43 cm, and 72 cm to 77 cm.

25.9 FUTURE PROSPECTS

In the mid- to long-term, the next steps are focused on setting up the NFI for the whole forest area. For this inventory to be implemented, human resources and a specific national budget are needed. The already-designed NFI will be multiobjective, covering different key aspects such as soil and biodiversity. To deal with the inaccessibility of the country, a thorough stratification should be further implemented. Due to the characteristics of the forest and the very limited financial resources for an NFI, Suriname aims to seek out the use of technology such as laser imaging, detection and ranging (LiDAR) or habitat mapping. This would be done in close collaboration with neighbouring countries within the Guiana Shield, considering a regional harmonization between the NFIs.

Regarding mangrove monitoring, additional parameters linked to the survival of mangrove forests and understorey will be considered in the future, such as water quality and salinity, which could provide insights regarding forest health. In addition, it would be desirable to include parameters such as the presence of crustaceans and fishes, which may further enhance the understanding of the biodiversity in the mangrove forests. Finally, including social parameters could shed light on the existing anthropogenic threats. For the 2021–2022 period, six new sampling units will be established within the mangrove forest and the existing sampling units will be remeasured to gain a better understanding of the dynamics within the mangrove forest.

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NEXT CHAPTER

URUGUAY

Chapter

URUGUAY

NATIONAL FOREST INVENTORY OF **URUGUAY**

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26.1 HISTORICAL OVERVIEW OF THE NATIONAL FOREST INVENTORY OF URUGUAY

The implementing body of national forest policy in Uruguay is the General Forestry Directorate (Dirección General Forestal – DGF, according to its acronym in Spanish) of the Ministry of Livestock, Agriculture and Fisheries (MGAP). In order to develop policies aimed at sustainable forest management, accurate information on the status of forests at the national level is critical. The national forest inventory (NFI) is an essential tool to achieve this goal.

Throughout its various inventory campaigns, the DGF has been the institution in charge of the inventory design, field data collection, and validation and processing of the information collected. The objective of the NFI is to provide adequate and updated information on the extent, characteristics and condition of the different types of forest (DGF, 2019).

Since its inception, the NFI has considered forests as a whole; therefore, both native forests and commercial plantations with alien species have been surveyed in the different campaigns. The technical team of the DGF considered that two different inventories with different objectives and expected results were needed to assess native forests and planted forests. This chapter presents the methodology and results of the NFI of native forests and the methodology used for the NFI of planted forests. Results are not yet available for the latter. As stated in the National Native Forest Strategy (NNFS), the state and vitality of native forests at the national level must be assessed more accurately (MGAP, 2018). Continuous monitoring through the installation of a network of permanent plots will provide information on the causes of forest fragmentation and degradation, as well as the gain or loss in land area of the different forest types.

26.2 TERMS AND DEFINITIONS RELEVANT TO THE IMPLEMENTATION OF THE NATIONAL NATIVE FOREST INVENTORY

Article 4 of Forestry Law No. 15.939 states the following:

> *Forests are vegetation associations dominated by trees of any size, whether they are harvested or not, and which are capable of producing timber or other forest products, or of influencing soil conservation, the water regime or climate, or that provide shelter or other benefits of national interest.*

The corresponding regulatory decree No. 452/988 adds that the minimum land area for a forest is 2 500 square metres (m²) (see Table 26.1).

The definition of "forest" poses certain challenges for representing all types of forests at map level with the available tools and spatial resolution of the images used. One example is "park forests," which may not be represented in the map due to their low level of tree cover per unit of land area; however, they meet the legal definition of forests and would thus be underestimated. Another example is the palm groves which,

although they have a distribution area close to 60 000 hectares (ha), their area of concentration with more than forty trees per hectare covers an area of about 16 000 ha.

A brief description of Uruguay's native forests is given in Box 26.1 below.

With respect to planted forests, according to the 2018 National Forest Mapping (DGF, 2018), these occupy a land area of 1 034 712 ha (6 percent of the entire national territory). Planted forests are composed of species of the genera *Eucalyptus* and *Pinus*, the main ones being *E. grandis, E. dunnii, E. globulus, P. taeda* and *P. elliottii*.

TABLE 26.1

Summary of definitions used to implement the National Native Forest Inventory

Term	Definition	Variables and thresholds
Forest	Forests are vegetation associations dominated by trees of any size, whether they are harvested or not, and which are capable of producing timber or other forest products, or of influencing soil conservation, the water regime or climate, or that provide shelter or other benefits of national interest. The minimum land area is 2 500 m^2 (Uruguay, 1998).	Predominance of trees ≥ 50% canopy cover and minimum of 200 trees/ha; with the exception of palm groves where 40 individuals/ha are considered (technical consensus) Minimum land area: 2 500 m^2 Trees: minimum total height at maturity from base to top of the crown ≥ 5 m (technical consensus) Shrub: maximum total height at maturity from base to top of the crown < 5 m (technical consensus) Minimum width: not defined Palm groves and psammophilous plants were not measured
Other wooded land	– Park forest[1] with low level of tree cover – Expanding forest with low density pioneer species – Mixed bushes, shrubs and low number of trees – Palm groves with less than 40 individuals/ha	Not considered
Other land	Isolated trees or trees that do not meet the minimum land area established for forest or other wooded land. It includes agricultural land, plains and grasslands, built-up areas, etc.	Not considered
Volume	Tree volume (m^3): Only species with a growth potential greater than or equal to 5 m in height at maturity are considered.	Minimum diameter at breast height (DBH, 1.30 m high) ≥ 3 cm with bark Total height: from the base to the top of the crown. Trees exceeding 1.30 m in height at the time of measurement. Form factor: 0.5 Species groups: all species identified in the field (genus and species). Does not include the volume of invasive alien species.
	Shrub volume (m^3): Only species with a growth potential of less than 5 m in height at maturity are considered.	DBH ≥ 3 cm with bark Total height: from the base to the top of the crown. Shrubs exceeding 1.3 m in height at the time of measurement. Form factor: 0.5 Species groups: all species identified in the field (genus and species).
Biomass	Above-ground biomass was estimated from the growing stock volumes by differentiating between above-ground and below-ground biomass.	Densities according to the most important species were used for the estimates.

Note: [1] See Box 26.1.

Source: Prepared by the authors with data from **Uruguay (Eastern Republic of).** *Law No. 15939. Forestry Law - Forest Fund - Natural Resources*, 1987.; **Uruguay (Eastern Republic of)**. Decree No. 452/988. Regulation of Forestry Law No. 15939, 1988.

Box 26.1 Native forests of Uruguay

According to the 2018 National Forest Mapping, native forest occupies an area of 835 349 ha (4.77 percent of the total national territory). It is a biodiverse ecosystem associated with the pampa and chaco biomes.

As described in the National Native Forest Strategy (ENBN) [(Estrategia Nacional de Bosque Nativo)], forest ecosystems are a relevant source of biological diversity. In their botanical composition, 136 tree species and 150 shrub species were identified, and about 50 percent of the birds and mammals identified in Uruguay inhabit the different native forests.

In addition to the environmental value that forests provide through various ecosystem services, such as the protection of several renewable resources, they also provide an economic value through the value chain of firewood as their main product. The development of the use or commercialisation of non-wood forest products is incipient and has great potential for research and development.

With regard to forest tenure, more than 95 percent of Uruguay's forests are located on privately owned land, where various agricultural and livestock production activities are carried out. Such activities have different interactions and impacts on the various types of forests.

The types of native forests in Uruguay, as presented in the ENBN, are classified as follows:

Gallery or riparian forests

The riparian forest is the most abundant type of native forest in Uruguay, associated with rivers and streams. Its presence and development depend mainly on the physical environment, which are the water flow and alluvial soils. It is characterized by a high level of regenerative growth and few monopodial trees, as a result of human intervention for firewood at varying degrees of felling and disturbance.

Mountain forest

The mountain forest is associated with the country's highest topographies, covering different sectors of the system of hills and mountain ranges. It generally develops on superficial soils and is made up of species that withstand periods of water scarcity.

Park forest

The park forest is located in areas near the banks of the Uruguay River, as a transition between the riparian forest and the herbaceous communities. These are xerophytic associations with a low density of trees.

Ravine forest

The ravine forest develops in moist areas with extreme topographic conditions (steep slopes) in the north and northeast of the country. It has subtropical characteristics, that is, a high density of tall species.

Palm groves

The palm groves in Uruguay are recognised for their scenic, cultural and biodiversity value. There are two communities in the country: in the east of the country, where the highest concentrations are found, and on the west coast. In the palm groves of the eastern region (*Butia odorata*), there is a nearly total absence of palms in the establishment phase and in the adult vegetative phase, which means that there are only adult palms between 200 and 300 years old. On the coast, the species is *Butia yatay*.

Coastal forest (psammophilous)

The coastal forest is characterized by its woody plant formations located on dunes on the banks of the La Plata River and the coast of the Atlantic Ocean.

Source: **DGF (General Forestry Directorate).** 2019. *Resultados del Inventario Nacional Forestal de Bosque Nativo: Etapas 2009-2016.* Montevideo. (pp 6-7).

FIGURE 26.1
Systematic sampling design based on forest mapping

Source: Prepared by the authors.

26.3 SAMPLING DESIGN

The NFI was based on a forest resource stratification system derived from the forest mapping that used the 2004 Landsat image classification.

A systematic sampling was developed using a grid of points that were located at a distance of 1.9 kilometres (km) from each other, covering the entire national territory. This grid was intercepted with the forest layer resulting from the mapping, thereby establishing the sampling units (plots) (Figure 26.1). The types of forest inventoried were native forest and planted forest. The approach to data collection was at the sub-basin level (Level 2).

The types of native forest surveyed were gallery forest, park forest, mountain forest and ravine forest. Psammophilous forests and palm groves were not considered, as they were not mapped due to their characteristics (small surface area or low canopy cover). For the planted forest with alien species, the following forest types were surveyed: commercial planted forests, shelter and shade forests for livestock, and other forests that provide other types of services.

The first and only NFI cycle was carried out by campaigns organized at the sub-basin level. The NFI of native forests was developed in three campaigns. The first campaign in 2009 was financed by the pilot reform process of the United Nations (UN) System "UN Joint Efforts – Delivering as One," whose framework agreement was signed between the United Nations and Uruguay. This agreement resulted in the 2007–2010 Joint Programme "Building Capacities for Development," which was financed by the Uruguay One UN Coherence Fund. During this campaign, 308 plots were surveyed in 11 sub-basins. The second campaign was carried out in 2011 and covered areas surrounding the previously surveyed basins. On that occasion, 198 plots were installed in another three sub-basins, with funding from the Inter-American Development Bank. Finally, the third stage was carried out between 2014 and 2016 with financial support from the World Bank, during which 959 plots were measured in the remaining 41 sub-basins. As a result of the three campaigns, a total of 1 465 sampling units were analysed for native forests with actionable information (Table 26.2).

The NFI of planted forests was also carried out in three campaigns with the same funding sources. During the first campaign in 2009, 757 sampling units were surveyed in 11 sub-basins. The second was carried out in 2011 and covered areas adjacent to the previously surveyed basins; 167 sampling units were installed in another three sub-basins. Finally, the third stage was carried out between 2014 and 2016, where 527 sampling units were measured in the remaining 41 sub-basins. This resulted in a total of 1 451 sampling units analysed for planted forest (Table 26.2).

The NFI of native forests was complex, given the high number of variables that were surveyed. Its main objectives were to contribute to knowledge about the evolution of forest resources and their environment, assess the state of forest conservation, quantify forest goods and services, quantify the growing stock volume of the different types of forests and, finally, support the preparation of national and international reports.

The specific objectives of the NFI of native forests were as follows:

- determine the stock and productive status by forest type (dendrometry, species, importance value index);
- serve as the basis to define measures for forest restoration;
- determine the state of forest degradation by examining invasive alien species and the state of natural regeneration.

Priority was given to variables that could be unified across all phases and that provide information to address most of the queries or information needs regarding native forests. These variables are intended to provide a qualitative and quantitative description of native tree composition, assessing floristic diversity and dasometric characteristics for the most important species of each type of forest and for the country's seven ecoregions. The database includes 1 465 sampling units distributed across the seven ecoregions.

The specific objectives of the NFI of planted forests were as follows:

- quantify the growing stock volumes of the different forest types;
- estimate current and future timber production;
- assess the forests' state of health;
- quantify forest goods and services.

The reason for not reporting on planted forests is explained by the dynamics and high growth rates of forest species in Uruguay; as a result, the established plots must be monitored at a frequency of no more than two years in order to achieve the expected objectives. One of the limitations to achieving the aforementioned objectives is the lack of funding to remeasure the established plots.

According to Table 26.3, the total number of sampling units between native and planted forests was 2 916, representing a total sampled land area of 1 050 000 ha, which represents 56 percent of the total forest area. When disaggregated by forest type, the surveyed area represents 64 percent of native forest at the national level, and 49.7 percent of planted forest.

TABLE 26.2

Historical overview of national forest inventories in Uruguay

National Forest Inventory	Implementation period	Scale	Sampling design	Number of sampling units implemented and actionable
First cycle	**2009–2016**	**National**	**Systematic**	**2 916**
Native forest				**1 465**
Campaign 1	2009–2010			308
Campaign 2	2011			198
Campaign 3	2014–2016			959
Planted forest				**1 451**
Campaign 1	2009–2010			757
Campaign 2	2011			167
Campaign 3	2014–2016			527

Source: Prepared by the authors with data from **DGF**. 2019. Resultados del Inventario Nacional Forestal de Bosque Nativo: Etapas 2009-2016. Montevideo.

TABLE 26.3

Characteristics of the sampling design for the National Forest Inventory

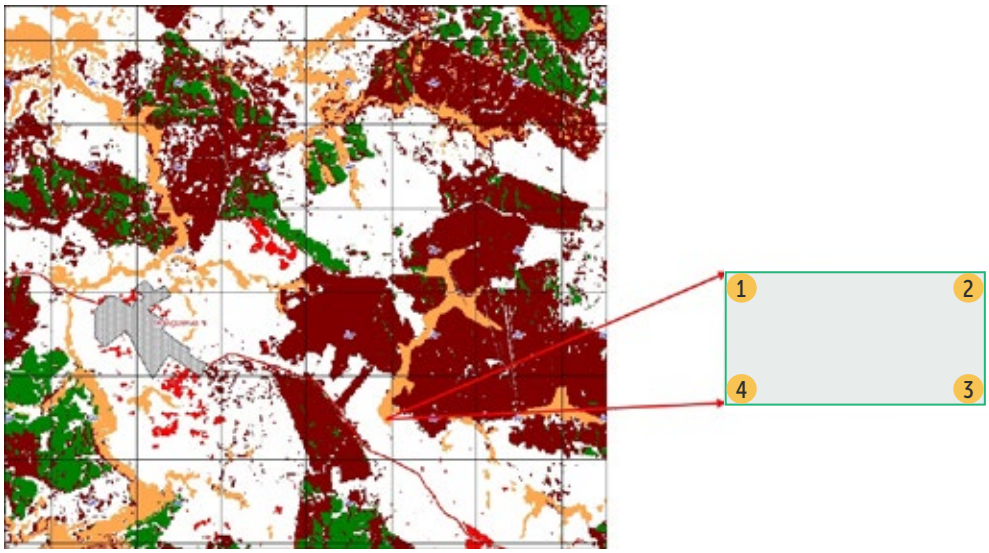
National Forest Inventory Campaign	Total land area (1 000 ha)	Number of sampling units			Total number of sampling units
		Forest (native and planted)	Other wooded land	Other land	
Campaign 1	384	1 065	n/a	n/a	1 065
Campaign 2	131	365	n/a	n/a	365
Campaign 3	536	1 486	n/a	n/a	1 486
Total	1 050	2 916	n/a	n/a	2 916

Note: n/a: not applicable.

Source: Prepared by the authors with data from **DGF**. 2019. Resultados del Inventario Nacional Forestal de Bosque Nativo: Etapas 2009-2016. Montevideo.

FIGURE 26.2

Type of plot for the National Native Forest Inventory



Source: Prepared by the authors.

26.4 SAMPLING UNIT DESIGN

26.4.1. NATIVE FORESTS

The sampling units correspond to individual rectangular plots measuring 20 m by 10 m, which is equivalent to a land area of 200 m². The following information was collected in each plot: dasometric information (diameter at breast height [DBH], total height), dendrological information (genus and species) for living trees and shrubs (according to the definitions mentioned above), and information on the environment and other variables that are detailed in section 26.5.3. To measure natural regeneration, two representative circular subplots (1–3 or 2–4) with a radius of 0.56 m were established, where trees less than 1.30 m in height were measured (Figure 26.2).

26.4.2. PLANTED FORESTS

The sampling units for planted forests were individual concentric circular plots of variable radius with a common centre. The radii measured 6 m, 10 m, 14 m and 18 m, respectively, corresponding to areas of 113 m², 314 m², 616 m² and 1 018 m², respectively (Figure 26.3).

Circular subplots with a radius of 6 metres (113 m²)

This is the first subplot to be recorded. The entire subplot is measured: all living trees higher than 1.30 m and with a DBH less than 0.10 m.

Circular subplots with a radius of 10 metres (314 m²)

Measured over the whole subplot: all living trees between 0.10 m and 0.25 m DBH.

Circular subplots with a radius of 14 metres (616 m²)

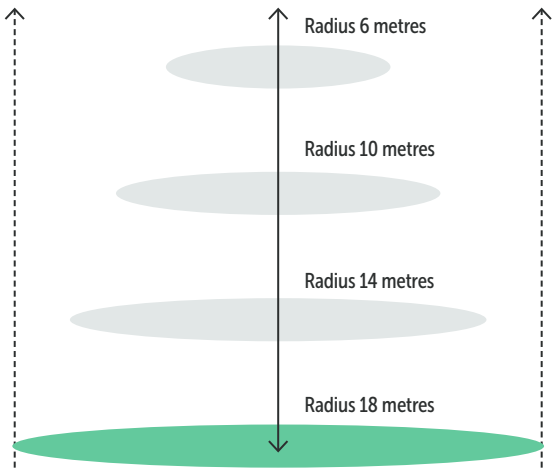
Measured over the whole subplot: all living trees between 0.25 m and 0.35 m DBH.

Circular plots with a radius of 18 metres (1 018 m²)

Measured over the whole plot: all living trees greater than 0.35 m DBH.

FIGURE 26.3

Type of plot for the National Planted Forest Inventory



Source: Prepared by the authors.

26.5 OTHER RELEVANT VARIABLES COLLECTED

Other variables assessed on each plot and in its surroundings were grouped as follows:

- general data: department, owner, name of the property, field team and date of completion;
- access and distances from the plot: geographical identification of the sampling point and access roads;
- water: type of associated flow (river, stream, gully, reservoir, etc.), water management, frequency (permanent or temporary), degree of contamination;
- fauna: type (mammals, birds, reptiles and amphibians), number of individuals observed, identification of genus and species;
- relief: location (flat, low, medium or high slope, summit), exposure (flat, east, west, south, north), slope form (concave, convex, linear);
- soil: soil group, erosion, depth, colour, texture, structure, stoniness, rockiness, drainage, infiltration;
- vegetation cover: degree of canopy, understorey and herbaceous cover;
- non-wood forest products (presence or absence): grazing (sheep, cattle, horses), beekeeping, mushroom gathering, seed collection, hunting, fishing and/or recreational activities;
- environmental problems associated with the area;
- fire: presence or absence; if present, type of fire;
- health of planted forests.

One variable that is considered relevant for native forests is the presence and severity of invasive alien species, as this is one of the main causes of native forest degradation. A list of these species is updated regularly by the Committee on Invasive Alien Species (Comité de Especies Exóticas Invasoras in Spanish), which is made up of various public institutions. The scientific names of these species were identified and their severity of threat to the area within the plot and its surroundings was classified according to the impact categories established by the International Union for Conservation of Nature:

- Slight: within the scope, the threat is capable of destroying or eliminating occurrences of an ecological community or ecosystem, or reducing the population of a species by 1 percent to 10 percent.
- Moderate: within the scope, the threat is capable of destroying or eliminating occurrences of an ecological community or ecosystem, or reducing the population of a species by 11 percent to 30 percent.
- Serious: within the scope, the threat is capable of destroying or eliminating occurrences of an ecological community or ecosystem, or reducing the population of a species by 31 percent to 70 percent.
- Extreme: within the scope, the threat is capable of destroying or eliminating occurrences of an ecological community or ecosystem, or reducing the population of a species by 71 percent to 100 percent.

26.6 LAND AREA, VOLUME AND BIOMASS CALCULATION

Table 26.4 shows the equations used to calculate the volume and biomass for each tree. The methodology for field data collection was based on paper spreadsheets, which were then digitally processed using Microsoft Access and Excel (2010 version).

26.7 RESULTS OF THE NATIONAL NATIVE FOREST INVENTORY

Table 26.5 shows the results for the following variables, which were measured in the 1 465 sampling units: total forest area, volume and living biomass. Of the total land area of native forest in the country, 37 percent has yet to be surveyed. The results for volume and biomass are broken down by the type of forest inventoried. These data are available by ecoregion (DGF, 2019). The results of tree volumes are presented in this publication, without considering shrub volumes.

TABLE 26.4

Equations used for volume and biomass calculations

Variables	Function	Reference
Land area	Each plot represents a land area of 361 ha Total land area of country: 17 502 000 ha	
Tree volume (m^3)	$V = BA \times Ht \times FF$ Where: *BA:* basal area (square metres) *Ht:* total height, in metres (to the top of the crown) *FF:* form factor = 0.5	There are currently no allometric equations for volume calculation available in Uruguay, even for the predominant species. Therefore, the form factor is generic for all identified species. This calculation method underestimates the growing stock volume of the different forests in the country.
Biomass (t)	Biomass was calculated by differentiating above-ground biomass from below-ground biomass. Biomass was estimated from the volumes of standing living trees. Densities in tonnes per cubic metre (t/m^3) were used for native forest estimates according to the most important species, which averaged 0.925 t/m^3.	
	BEF (biomass expansion factor) used for native forest = 1.2 Above-ground biomass = dry matter × BEF (biomass expansion factor = 1.2)	IPCC (2003)
	Roots biomass = above-ground biomass × R (root-shoot ratio = 0.24)	IPCC (2006)

Source: Prepared by the authors with data from **IPCC (Intergovernmental Panel on Climate Change).** 2003. *Good Practice Guidance for Land Use, Land-Use Change and Forestry* In: J. Penman, M. Gutarsky, T. Hiraishi, T. Krug, D. Kruger, R. Pipatti, L. Buendia, et al., eds. Hayama, Japan, Institute for Global Environmental Strategies.; **IPCC.** 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories – A primer.* In: Eggleston H.S., Miwa K., Srivastava N. and Tanabe K., eds. Hayama, Japan, Institute for Global Environmental Strategies.

TABLE 26.5

Results of the National Native Forest Inventory for all stages

Variables	Results
Total land area inventoried, in hectares, based on the land area of a sampling unit and the number of completed sampling units	528 865 ha
Total land area inventoried (%) in relation to the total land area of native forests	64%
Total land area inventoried (%) per forest type	Riparian forest: 82% Park forest: 5% Mountain forest: 9% Ravine forest: 4%
National average tree volume, in cubic metres per hectare (m^3/ha)	105 $\pm$ 4 m^3/ha
National average tree volume per forest type (m^3/ha)	Riparian forest: 113 m^3/ha Park forest: 26 m^3/ha Mountain forest: 84 m^3/ha Ravine forest: 103 m^3/ha
National average tree biomass (including above-ground and below-ground biomass), in tonnes per hectare (t/ha)	145 t/ha
National average tree biomass per native forest type (includes above-ground and below-ground biomass) (t/ha)	Riparian forest: 156 t/ha Park forest: 35 t/ha Mountain forest: 115 t/ha Ravine forest: 141 t/ha

Source: Prepared by the authors with data from **DGF**. 2019. Resultados del Inventario Nacional Forestal de Bosque Nativo: Etapas 2009-2016. Montevideo.

26.8 IMPLEMENTATION AND QUALITY CONTROL

The implementation of the NFI of native forests varied according to each the three stages implemented:

- Campaign 1 (2009): national experts from the forestry sector were hired to establish the sampling units in the field and to measure them. The information was collected using paper forms and processed in Microsoft Access (2010 version). The funds were managed by the Food and Agriculture Organization of the United Nations (FAO). Vehicles and measurement tools were purchased.
- Campaign 2 (2011) and Campaign 3 (2014–2016): national companies were contracted to carry out the installation of field sampling units and their measurement. The information was collected on paper forms and processed in Microsoft Excel (2010). The funds were managed by MGAP.

All the stages carried out in the framework of the NFI were surveyed and monitored by DGF technicians. At least 10 percent of the plots were verified to corroborate the quality of the data collected in the field.

During the last stage of the NFI of native forests, a software was developed for collecting and processing field data. However, the software was difficult to implement due to a lack of computer technicians.

26.9 FUTURE PROSPECTS

The NFI of native forests has represented an important human and financial effort and has been a valuable learning process. While there are aspects to improve, this is part of the process required to have an NFI that adapts to Uruguay's forest monitoring needs.

Drawing on the information that has been generated and the field experience that has been gained during these years, the design of the NFI can be reconsidered. In the future, a statistical analysis of

the different variables for each type of forest and for each ecoregion will be necessary, in order to adjust the number of sampling units to be established, as well as to explore new forms and sizes of sampling units.

In order to ensure the continuity and frequency of remeasurement, a cost-benefit analysis will need to be conducted for the variables of less relevance and in lower demand. At the same time, new variables will have to be included to respond to current information needs (such as invasive alien species in native forest ecosystems and carbon in forest biomass, among others).

Funding sources must be secured to ensure the frequency and continuity of the NFI. The inventory should be permanent in order to establish a reliable monitoring mechanism and generate early warnings to improve short- and medium-term forest management.

Variables should be harmonized with other countries in the region, especially with those that share similar floristic composition, which will facilitate their analysis for international organizations.

At present, the DGF is using the Open Foris package developed by FAO, specifically Collect and Collect Mobile, as a tool to collect and process inventory data.

Finally, it is worth highlighting the donation of measuring instruments received from FAO in 2017, through the project "National Forest Monitoring and Information Systems for a transparent and accurate REDD+ process."

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NATIONAL FOREST INVENTORIES OF LATIN AMERICA AND THE CARIBBEAN

Towards the harmonization of forest information

National forest inventories (NFIs) are one of the main sources of forest information. This book describes the importance and history of NFIs in Latin America and the Caribbean, a region that is particularly relevant due to the extent and biodiversity of its forests. Methodologies for data collection and measurement of the most important indicators in 21 countries are addressed. In addition, the similarities and differences in the designs of NFIs, challenges and opportunities, and perspectives for the future are examined. This analysis demonstrates that the information generated by countries is diverse and must be harmonized to satisfy the commitments and opportunities for sustainable forest management in the twenty-first century. This publication represents a milestone in beginning the harmonization process towards data transparency within the forestry sector in Latin America and the Caribbean and constitutes the first collaborative effort of a network of NFI experts and collaborators in the region.

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