Chapter

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

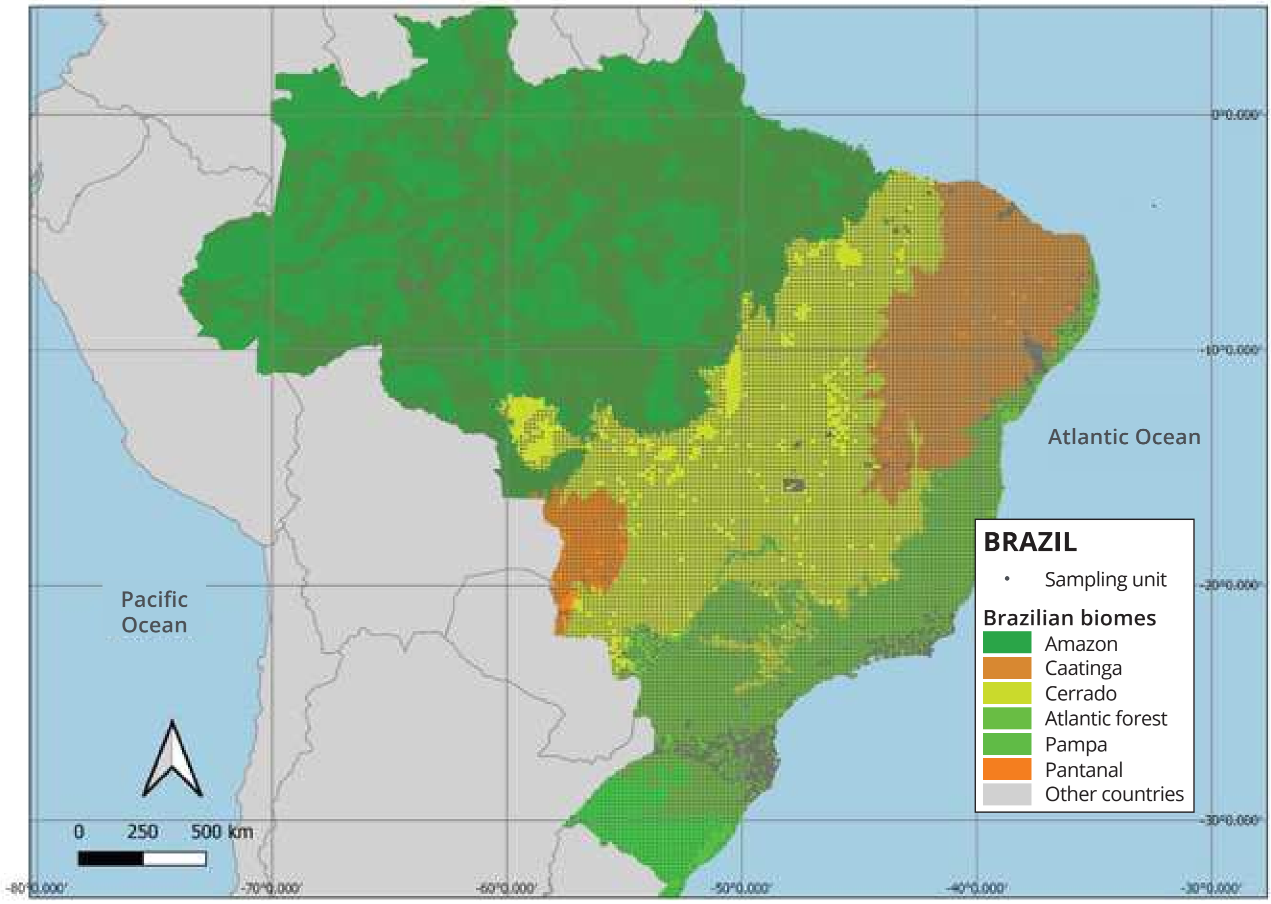
Description of the ongoing first cycle of the Brazilian National Forest Inventory

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. Brasilia, 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

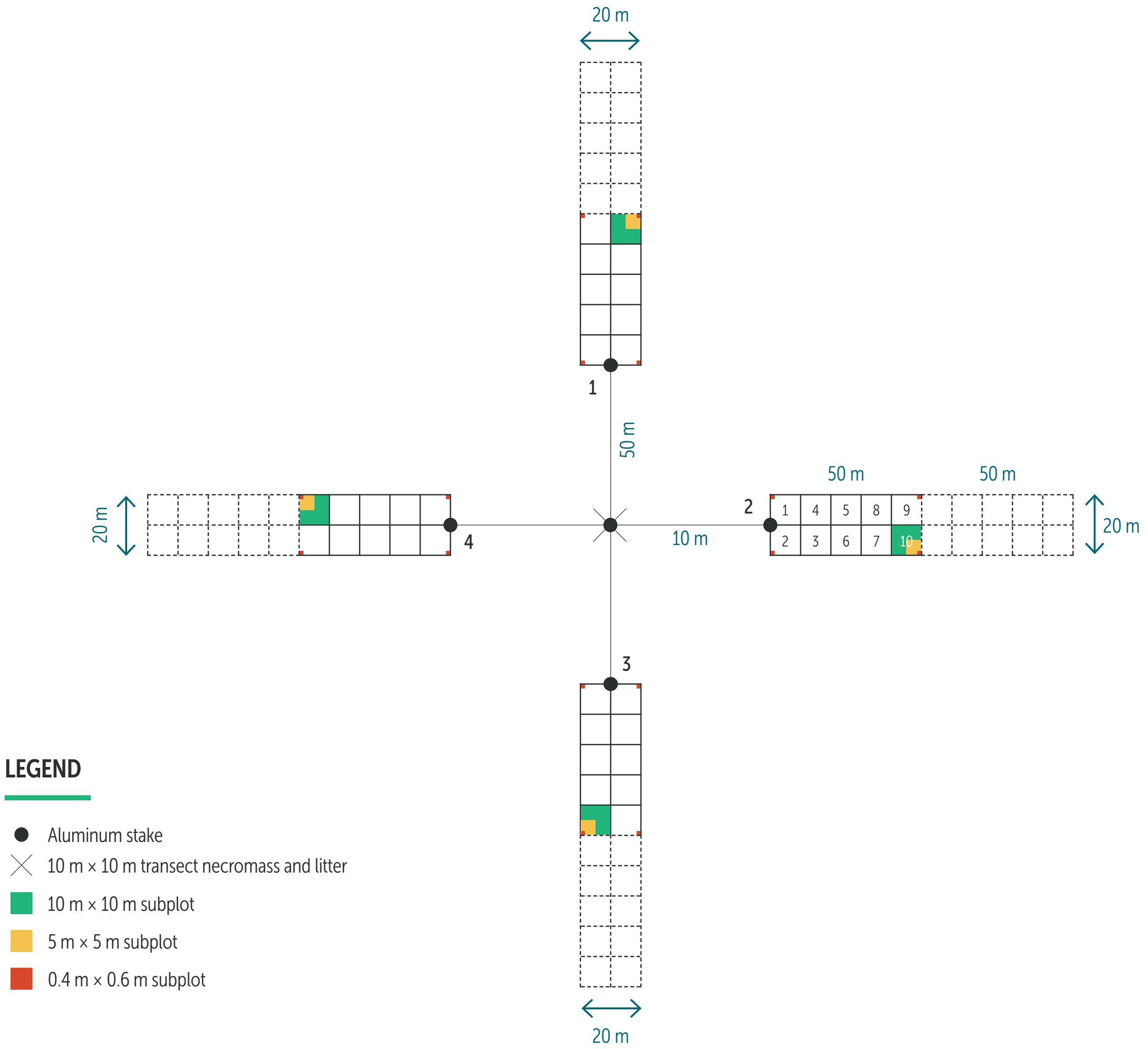
Dimensions of the sampling unit and subdivisions to address various levels of inclusion

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.

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.

REFERENCES

Bauch, S., Sills, E., Rodriguez Estraviz, L.C., McGinley, K. & Cubbage, F. 2009. Forest policy reform in Brazil. *Journal of Forestry*, 107(3): 132–138. https://academic.oup.com/jof/article-pdf/107/3/132/22609345/jof0132.pdf

Canteiro, C., Barcelos, L., Filardi, F., Forzza, R., Green, L., Lanna, J., Leitman,, P. *et al*. 2019. Enhancement of conservation knowledge through increased access to botanical information. *Conservation Biology*, 33(3): 523–533. https://doi.org/10.1111/cobi.13291

FAO. 2005. *Global Forest Resources Assessment 2005: Progress towards sustainable forest management.* Rome, FAO. www.fao.org/3/a0400e/a0400e.pdf

FAO. 2010. *Global Forest Resources Assessment 2010: Terms and Definitions.* Forest Resources Assessment Working Paper 144/E. Rome, FAO. www.fao.org/3/am665e/am665e00.pdf

FAO. 2020a. *Global Forest Resources Assessment 2020: Main report.* Rome, FAO. https://doi.org/10.4060/ca9825en

FAO. 2020b. *Global Forest Resources Assessment 2020. Report – Brazil*. Rome, FAO. www.fao.org/3/ca9976en/ca9976en.pdf

IBGE (Brazilian Institute of Geography and Statistics). 2012. *Manual técnico da vegetação brasileira. 2nd Ed.* Rio de Janeiro, Brazil, IBGE. https://biblioteca.ibge.gov.br/visualizacao/livros/liv63011.pdf

IBGE. 2018. Desbravar, conhecer, mapear: Memórias do Projeto Radam/RadamBrasil. Memória Institucional 24. Rio de Janeiro, Brazil. https://biblioteca.ibge.gov.br/visualizacao/livros/liv101614.pdf

Machado, S.A. 1984. *Inventário Florestal Nacional das florestas plantadas nos Estados Paraná e Santa Catarina.* Brasilia, Brazilian Institute for Forest Development.

MMA (Ministry of Environment). 2016. *Estratégia do Programa de Monitoramento Ambiental dos Biomas Brasileiros.* Brasilia, MMA. https://snif.florestal.gov.br/images/pdf/publicacoes/estrategia_programa_monitoramento_ambiental_biomas.pdf

Queiroz, W.T. 2012. *Amostragem em Inventário Florestal.* Belém, Brazil, Federal Rural University of Amazonia. https://files.cercomp.ufg.br/weby/up/417/o/amostragem_inventario_florestal_Waldeney_UFRA_2012.pdf

Rosot, M.A.D., Maran, J.C., Luz, N.B., Garrastazu, M.C., Oliveira, Y.M.M., Franciscon, L., Clerici, N., Vogt, P. & Freitas, J.V. 2018. Riparian forest corridors: A prioritization analysis to the Landscape Sample Units of the Brazilian National Forest Inventory. *Ecological Indicators*, 93: 501–511. https://doi.org/10.1016/j.ecolind.2018.03.071

SFB (Brazilian Forest Service). 2016. *Inventário Florestal Nacional: principais resultados – Distrito Federal.* Brasilia, Ministry of Agriculture, Livestock and Supply. https://ifn.florestal.gov.br/documentos/informacoes-florestais/inventario-florestal-nacional-ifn/resultados-ifn/1793-relatorio-inventario-florestal-nacional-df/file

SFB. 2017. *Inventário Florestal Nacional: principais resultados – Sergipe*. Brasilia, Ministry of Agriculture, Livestock and Supply. www.florestal.gov.br/documentos/informacoes-florestais/inventario-florestal-nacional-ifn/resultados-ifn/3532-relatorio-ifn-se-2017/file

SFB. 2018. *Inventário Florestal Nacional: principais resultados – Santa Catarina.* Brasilia, Ministry of Agriculture, Livestock and Supply. www.florestal.gov.br/documentos/informacoes-florestais/inventario-florestal-nacional-ifn/resultados-ifn/3656-relatorio-ifn-sc-2017/file

SFB. 2019a. *Inventário Florestal Nacional: principais resultados – Município de Caçador – SC*. Brasilia, Ministry of Agriculture, Livestock and Supply. www.florestal.gov.br/documentos/publicacoes/4167-relatorio-tecnico-ifn-cacador-digital/file

SFB. 2019b. *Inventário Florestal Nacional: principais resultados - Terra Indígena Mangueirinha.* Brasilia, Ministry of Agriculture, Livestock and Supply. www.florestal.gov.br/documentos/publicacoes/4220-relatorio-ti-mangueirinha-versao-online/file

SFB. 2019c. *Manual de Campo: procedimentos para a coleta de dados biofísicos e socioambientais.* Brasilia, Ministry of Agriculture, Livestock and Supply. www.florestal.gov.br/publicacoes-ifn/1612-anual-de-campo-procedimentos-para-coleta-de-dados-biofisicos-e-socioambientais

SFB. 2019d. *Florestas do Brasil em Resumo: 2019.* Brasilia, Ministry of Agriculture, Livestock and Supply. www.florestal.gov.br/publicacoes/1737-florestas-do-brasil-em-resumo-2019

Shiver, B.D. & Borders, B.E. 1995. *Sampling Techniques for Forest Resource Inventory.* New York, USA, John Wiley & Sons.

Silva, J.A. 1996. *Análise quali-quantitativa da extração e do manejo dos recursos florestais da Amazônia brasileira: uma abordagem geral e localizada (Floresta Estadual do Antimari – AC).* Federal University of Paraná. PhD dissertation.

ter Steege, H., Pitman, N.C.A., Sabatier, D., Baraloto, C., Salomão, R.P., Guevara, J.E., Phillips, O.L., *et al.* 2013. Hyperdominance in the Amazonian Tree Flora. *Science*, 342(6156): 1243092. http://doi.org/10.1126/science.1243092

SUDAM (Superintendence for the Development of the Amazon). 1974. *Levantamentos florestais realizados pela Missão FAO na Amazônia (1956-1961).* Belém, Brazil.

Vibrans, A.C., Sevgani, L., Lingner, D.V., Gásper, A.L. & Sabbagh, S. 2010. Inventário florístico florestal de Santa Catarina: aspectos metodológicos e operacionais. *Pesquisa Florestal Brasileira*, 30(64): 291–302.

Vibrans, A.C., Moser, P., Oliveira, L.Z. & Maçaneiro, J.P. 2015. Generic and specific stem volume models for three subtropical forest types in southern Brazil. *Annals of Forest Science*, 72: 865–874. http://doi.org/10.1007/s13595-015-0481-x