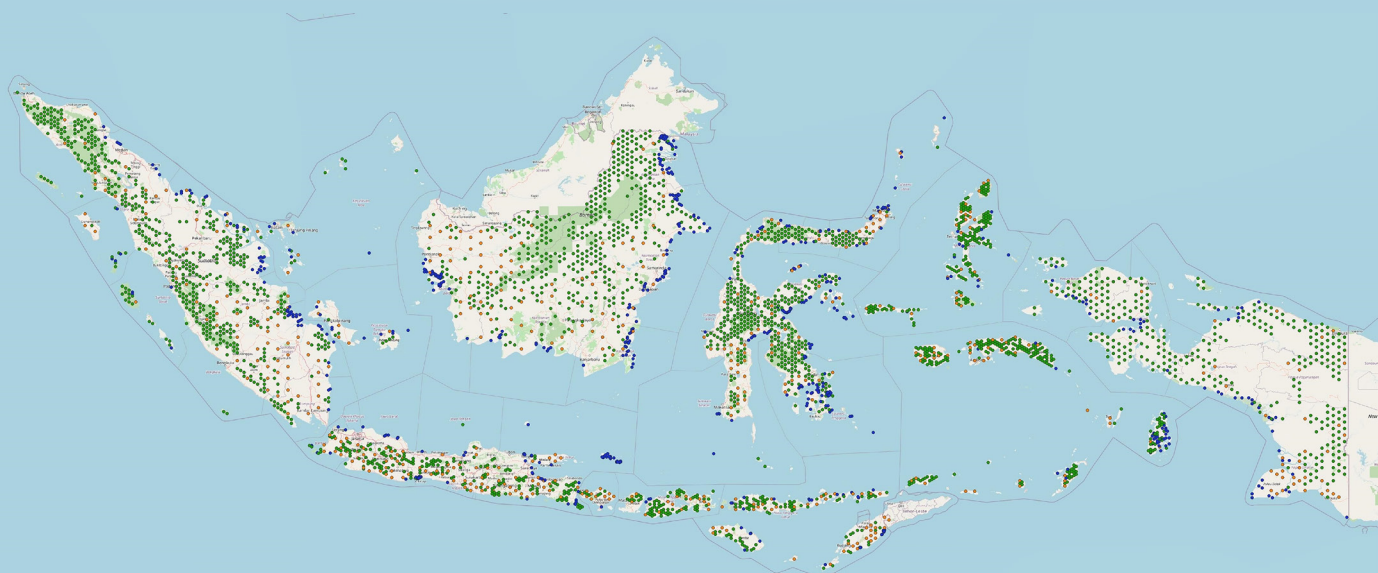




National Forest Inventory for Indonesia

Design and planning of a new national scale
forest inventory for multiples purposes



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Food and Agriculture Organization of the United Nations

2024

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Compiled by:

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Contents

Acronyms	v
1 INTRODUCTION and BACKGROUND	1
2 PLANNING AND DESIGN OF THE NATIONAL FOREST INVENTORY	3
2.1 Needs assessment for the new Indonesian National Forest Inventory	3
2.1.1 Information needs assessment	3
2.1.2 Reporting units for the NFI	5
2.2 Planning principles	6
2.3 Objectives and purposes of the Indonesian NFI	8
2.3.1 Expected design features of the new Indonesian NFI	8
2.3.2 Objectives of the Indonesian NFI	8
2.4 Sampling design	9
2.4.1 Sample size calculations and stratification	9
2.4.2 Sampling strategy	13
2.5 Estimation design	18
2.5.1 Expected outputs	18
2.5.2 Area related estimates and ratio estimators	18
2.5.3 Estimates at the tree level	20
2.5.4 Estimates for other population parameters	22
2.5.5 Uncertainty estimates	24
2.5.6 Considerations derived from division of the sampling frame into yearly panels	25
3 Implementation of the new National Forest Inventory	27
3.1 Road map for the National Forest Inventory of Indonesia	27
3.2 Division of the sampling frame into five annual panels	29
3.2.1 Distribution of panels and samples over islands, strata, land classes and BPKHTL units	29
3.3 Quality assurance and quality control	35
3.4 Data management and data analysis	35
3.4.1 Software tools for data collection, uploading and storage	35
3.4.2 Data analysis	38
4 References	39
5 Annexes	41
5.1 Sample size calculation	41
5.2 Maps of NFI cluster distribution and panels	44

List of Figures and Tables

Figures

1	Overlay of dryland forest NFI cluster over a 1 ha interpretation window of Collect Earth	11
2	Geometry of the hexagon-based sampling frame of the Indonesian NFI	14
3	Cluster design of field plots for the new Indonesian national forest inventory	15
4	Cluster design of field plots for all three strata of the new Indonesian NFI	16
5	Overview field data and observable variables to be collected for the Indonesian NFI	17
6	Intersection length and tilt angle in CDW measurements	22
7	Implementation process of the Indonesian NFI	27
8	NFI sample units distributed over five panels at national scale	31
9	Open Foris software tools for forest inventory and forest monitoring	36
10	OF Collect Survey Designer for developing electronic field forms for data collection	36
11	Collect Mobile app of the Indonesian NFI on a PDA (tablet, mobile phone)	37
12	Data cleansing module for field data with Collect	37
A1	NFI cluster distribution all strata and all panels	44
A2	NFI cluster distribution stratum 1 (dryland, swamp and plantation forests) on all panels	45
A3	NFI cluster distribution stratum 2 (trees outside forests) on all panels	46
A4	NFI cluster distribution stratum 3 (mangrove forests) on all panels	47

Tables

1	Results information needs assessment	3
2	Principles for designing a national forest monitoring system	7
3	First draft proposal sample sizes for Indonesian NFI	9
4	Results of phase 1 sampling	10
5	Initial results sample size calculations with IPSDH	12
6	Final sample size calculation (number of clusters) after iterative plot analysis	13
7	Decay classes and reduction factors for wood density in lying CDW	23
8	Percentage share of samples for the five panels of the first measurement cycle	30
9	Division of the NFI sample frame into five annual panels	30
10	Distribution of NFI clusters over BPKH areas	32
11	Initial weighting factors w_i for panels of the Indonesian NFI	34
12	Expected sampling error SE_{pj} for key variable AGB for individual panels at scales of islands	34
13	Expected sampling error SE_{pj} for key variable AGB for panels at national scale	34
A1.	Sample size and hexagon spacing for Stratum 1 (dry land, swamp, and plantation forests)	42
A2.	Sample size and hexagon spacing calculations for Stratum 2 (trees outside forest, TOF)	42
A3.	Sample size and hexagon spacing calculations for Stratum 3 (mangrove forest)	43

Acronyms

AGB	Above ground biomass
BA	Basal area
BGB	Below ground biomass
BPKH	<i>Balai Pemantapan Kawasan Hutan</i> (Forest Area Consolidation Centre)
BRGM	<i>Badan Restorasi Gambut dan Mangrove</i> (Peat and mangrove restoration agency)
CE	Collect Earth
CEO	Collect Earth Online
CFI	Continuous forest inventory
COP	Conference of parties
CWD	Coarse deadwood
DBH	Diameter at breast height
DRF	Decay reduction factor
EF	Emission factor
E%	Sampling error in percent of the mean
FAO	Food and Agriculture Organization of the United Nations
FOLU	Forestry and other land uses
GEDI	Global Ecosystem Dynamics Investigation
GHG-I	Greenhouse gas inventory
GPS	Global positioning system
HGU-PEMDA	<i>Hak Guna Usaha – Pemerintah Daerah</i> (Cultivation right – local government)
HPK-HP	<i>Hutan Produksi Konversi – Hutan Produksi</i> (convertible production forest)
IPSDH	<i>Direktorat Inventarisasi dan Pemantauan Sumberdaya Hutan</i> (Directorate of Forest Resources Inventory and Monitoring)
ISEA3H	Icosahedral Snyder Equal Area Aperture 3 Hexagonal Grid
KLHK	<i>Kementerian Lingkungan Hidup dan Kehutanan</i> (Ministry of Environment and Forestry)
KPHP – RE	<i>Kesatuan Pengelolaan Hutan Produksi – Restorasi Ekosistem</i> (Production forest management unit – ecosystem restoration)
KPHP-HTI	<i>Kesatuan Pengelolaan Hutan Produksi – Hutan Tanaman Industri</i> (Production forest management unit – industrial forest)
KPHP-PIAPS	<i>Kesatuan Pengelolaan Hutan Produksi - Peta Indikatif dan Area Perhutanan Sosial</i> (Production forest management unit – social forestry)
LIS	Line intersect sampling
LTS-LCCR	Long-term strategy low carbon and climate resilience
LULUCF	Land use, land use change and forestry
MA	Moving averages (method)
MoEF	Ministry of Environment and Forestry
MRV	Measuring, reporting and verification
NASA-SRTM	NASA shuttle radar topography mission
NDC	Nationally determined contributions
NFI	National Forest Inventory
NFMS	National forest monitoring system

Continue to next page

NTFP	Non-timber forest products
OF	Open Foris
PDA	Personal digital assistant
PHL-PIAPS	<i>Pengelolaan Hutan Lestari – Peta Indikatif dan Area Perhutanan Sosial</i> (sustainable forest management – indicative map of social forestry area)
PSP	Permanent sample plot
QA/QC	Quality assurance/ quality control
REDD+	Reducing emissions from deforestation and forest degradation, and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks
RF	Removal factor
SD	Standard deviation
SE	Standard error
SFC	Space filling curve
SLMS	Satellite based land monitoring system
SOC	Soil organic carbon
SOP	Standard operation procedure
SRN	Sistem Registri Nasional (National Registry System for Climate Change)
SRS	Simple random sampling
TI	Temporally indifferent (method)
TOF	Trees outside forests
TSP	Temporary sample plot
UNFCCC	United Nations framework convention on climate change
VAR	Variance

1 INTRODUCTION and BACKGROUND

Indonesia's forests are an important national resource from a socioeconomic and biodiversity perspective. They are also globally significant in terms of the protection of endemic and endangered biodiversity, and have huge potential for reducing GHG emissions.

The Indonesian Government has made strong and ambitious commitments in terms of contributing to international efforts to mitigating and adapting to Climate Change. The emission reduction targets of the 2022 enhanced Indonesian NDC (Republic of Indonesia 2022) amount to 31.89 % of GHG emission reduction by 2030 (unconditional) and up to 43.2 % with international support (conditional). Nearly all GHG emission (97.2%) in Indonesia are related to land use, land use change and forestry and the energy sectors with ca 58% of the 10-year (2021-2030) emission reduction targets expected to come from the Forestry and Land Use sector (FOLU)¹.

For the forestry sector, Indonesia has set up ambitious quantitative targets by 2030 in peat land restoration of 2 million ha and rehabilitation of degraded land of 12 million ha. The country also recognises the important roles of forests and REDD+ for achieving the targets of the LULUCF sector. The national REDD+ strategy (MoEF 2022a) is in the stage of implementation in the context of achieving the NDC targets and the targets from the Forestry and Other Land Use (FOLU) net sink 2030 operational plan (MoEF 2022b).

In order to support the required improvement in measuring, reporting and verification (MRV) for Climate Change reporting for the LULUCF/FOLU sector, the country has been working in enhancing its national capacities considering relevant COP decisions on REDD+ and MRV (e.g. Warsaw Framework, Paris Agreement). Reliable data of GHG emissions for the LULUCF sector are dependent on having accurate estimates from a National Forest Monitoring System (NFMS) for both land area data (activity data) and carbon densities on land areas (emission factors) and their changes over time.

The key components of an NFMS are (1) a National Forest Inventory (NFI) and (2) a satellite-based land monitoring system (SLMS). For the latter, Indonesia has improved progressively its national capacities over the last years. The NFI component of the NFMS, however, has been largely unchanged in design and scope since its inception in the late 1980s.

Since 2021, upon the request by the Government of Indonesia and with financial support through the Government of Norway, FAO has been working together with the Ministry of Environment and Forestry (MoEF) in redesigning the NFI component of the NFMS with the objective of developing an efficient NFI approach in terms of scope and design that is responsive to new and emerging measuring and reporting requirements, especially for Climate Change reporting².

¹ Indonesia's Long-Term Strategy Low Carbon and Climate Resilience 2050 (LTS-LCCR 2050) submitted to the UNFCCC in 2021 is expected to achieve net sink status of the FOLU sector from 2030 onwards.

² (FAO and MoEF 2021) Project document: Strengthening Indonesian Forest and Land Monitoring for ClimateActions (GCP/INS/087 /NOR). Jakarta. 68 pp

The ultimate goal of this initiative is to support the country in establishing measurement systems that can deliver reliable and accurate data on emission reductions and provide confidence in the results. The latter is key for access to climate finance such as REDD+ results-based payments.

This document describes the rationale for the redesign process and a description of all major decisions in terms of design, scope and measurement variables for the NFI including elements for the estimation design and operational implementation planning as far as feasible during the remaining running time of the project (June 2024).

2 PLANNING AND DESIGN OF THE NATIONAL FOREST INVENTORY

2.1 Needs assessment for the new Indonesian National Forest Inventory

2.1.1 Information needs assessment

In 2022 a comprehensive information needs assessment for the new NFI was carried out (Tiryana 2022). A process of 4 focus group discussions or workshops with relevant public and private stakeholders from different administrative and territorial levels, different decision-making levels and with different backgrounds and interests relevant for a new national scale forest inventory was carried out during a two months' time. In some cases, the focus group discussions were followed up on with online questionnaires for clarifying purposes.

The results from this needs assessment study can be summarized as follows (table 1).

Table 1 Results information needs assessment

Information category	Forest and land attributes	Relevant forest and land types
Tree level data	Timber volume and other stand level attributes (species, timber quality, height, etc), biomass, carbon stocks	All forest types ³ and all ownership types (state, customary, private)
Non-timber forest products (NTFPs)	Naturally occurring NTFPs (rattan, bamboo, lianas, nipa, sago, etc), species, biomass, carbon stocks	All forest types and ownership types, except watershed protection forests
Biodiversity	Diversity of Flora and Fauna	All forest types and all ownership types (state, customary, private)
Site conditions	Abrasion/ erosion	Watershed protection forests
	Depth of peat	Peat and swamp forests
	Critical lands	Watershed protection forests
	Disaster prone areas ⁴	Watershed protection forests
	Land cover	All forest types and ownership types
	Soil types and biophysical attributes	All forest types, except mangroves, peat and swamp forests ⁵
	Topography (slopes and altitudes)	Watershed and customary forests ⁶

Continue to next page

3 Production forests, protected forest, conservation forests, mangroves, peat and swamp forests, watershed protection forest,

4 probably referring to abrasion/ erosion or land slide prone areas

5 Probably due to the lack of consciousness by workshop participants about the importance of soil and sediment data for soil organic carbon stock calculations (SOC) in mangrove and swamp forests or budgetary concerns or both

6 Unclear why only in these two types, should be measured on all sites

Table 1 (Continued)

Information category	Forest and land attributes	Relevant forest and land types
Environment	Water quality, rainfall, water debit, erosion	Watershed protection forests, water quality also in protected forests
	Environmental services/ ecotourism	All forest and ownership types
Social	Community access to forests	All forest types, except mangrove, peat and swamp forest and watershed protection forests
	Community governance	Customary and private forests
	Land conflicts	All forest and ownership types except protected forests
	Utilization forms	Mangroves, customary and private forests
	Encroachment	Production forests
	Legal permits	All forest and ownership types
	Socio economic ⁷	All forest types, except mangroves and peat and swamp forests
	Ownership status	Customary and private forests

Source: Tiriyana 2022

However, from table 1 it can be seen that for covering the information needs of the environment and social category a socio-economic survey component with standardized questionnaire-based interviews would have to be developed. The information needs from table 1 were therefore tailored down to information needs and corresponding attributes and variables to be measured to what a biophysical survey only could deliver as no socio-economic survey is planned as part of the new NFI.

In addition, likely budgetary limitation in the government also indicated to reduce the scope of information needs to be covered by the new NFI to what strictly is necessary for climate change reporting and for national forest policy purposes.

Therefore, in discussions with FAO and IPSDH⁸, three main objectives for the new NFI were defined:

- Estimation of forest growing stock (timber volume), forest biomass and carbon stock, NTFP potential, and their growths at the level of state, customary, and private forests
- Assessment of floral diversity in the state, customary, and private forests
- Assessment of land cover conditions at the level of state, customary, and private forests.

NTFP measurements are only included for the most important ones such as rattan, bamboo, nipa and sago. Soil and sediment measurements, although recognised as important, are not included at this stage of the new NFI development (budget limitations).

In addition to the information needs assessment as such, issues and difficulties from past NFI implementation in terms of design (lack of representation of certain land cover/forest types), practical measurement and data collection issues (e.g. tree height measurements, species identification) or other issues (moving plot locations by field crews⁹) were identified for consideration in the new design and the new field instructions.

⁷ Unclear what specifically is meant by this

⁸ Direktorat Inventarisasi dan Pemantauan Sumberdaya Hutan (IPSDH)

⁹ This should never be done by field crews! Inaccessible cluster and plot locations are to be treated as non-response and not be moved arbitrarily to other locations.

Also, major issues related to data processing and data analysis came up during the assessment. Particularly worrying in this context is that apparently data from temporary sample plots (TSPs) of the old NFI measurement cycles, with the exception of the first one (1989-1996), were never analysed, only data from permanent sample plots (PSPs)¹⁰.

It was therefore that needs for the new NFI were also formulated for establishing better data processing, analysis and data management facilities with the following elements:

- Unifying system for all 22 BPKH¹¹ offices in charge of field data collection for paperless data collection, uploading and storage
- Development of a dedicated NFI data base and forest information system
- Development of standardized calculation chains for NFI data analysis for estimating growing stocks and other relevant forest attributes (biomass, carbon stock)
- A data analysis system for modelling forest growth
- A system for integrating of remote sensing and terrestrial data for estimating forest resource attributes (e.g. for inaccessible forest areas)

Other requirements for the new NFI as formulated from the needs assessment were:

- Provide forest biomass and carbon stock data from private and community forests (not only state forests)
- The NFI should be integrated with province and watershed level forest inventories in the sense that intensifying sampling in certain land areas or reporting units could be done in consistency with the NFI grid of sampling locations.

2.1.2 Reporting units for the NFI

2.1.2.1 Land and forest cover classes

The land and forest cover classes defined by the Ministry of Environment and Forestry (MoEF-KLHK) for which NFI results need to be produced are the following:

- Primary dryland forest (Hutan Lahan Kering Primer)
- Secondary dryland forest (Hutan Lahan Kering Sekunder)
- Primary swamp forest (Hutan Rawa Primer)
- Secondary swamp forest (Hutan Rawa Sekunder)
- Primary mangrove forest (Hutan Mangrove Primer)
- Secondary mangrove forest (Hutan Mangrove Sekunder)
- Plantation forests (Hutan Tanaman)

In addition, the new NFI will include Trees outside Forests (TOF) too. Trees outside forests can be found on the following land classes:

- Pure agriculture (Pertanian Lahan Kering)
- Mixed dry agriculture (Pertanian Lahan Kering Bercampur Semak)
- Dry shrub (Semak/ Belukar)
- Wet shrub (Semak Belukar Rawa)

¹⁰ This would mean that from 9 plots within the old NFI cluster, data from 8 plots within the cluster would not have been used for analysis (at least not after 1996).

¹¹ Balai Pemantapan Kawasan Hutan (BPKH)

2.1.2.2 Reporting units from Indonesia's emission reduction targets for LULUCF

The targets from Indonesia's NDC commitments for the FOLU sector are broken down through the Operational Plan Indonesia's Net Sink 2030¹² for five main mitigation actions:

- Emission reduction from deforestation and forest degradation
- Establishment of plantation forests
- Sustainable forest management
- Forest rehabilitation
- Peatland management

The 2030 targets are formulated as land area targets in hectare for 13 management types¹³ and 7 mitigation action programmes¹⁴.

The NFI results will then primarily provide the emission factors (EFs) in terms of C-stock and stock changes per ha and reporting unit.

The results of the NFI (annually and periodically) in terms of EFs would be presented as part of the Annual Greenhouse Gas Emission Report for the FOLU sector and the Mitigation Action Implementation Report of the FOLU net sink 2030 operational plan. The corresponding area and area change data (activity data, AD) should come from the satellite-based land monitoring system (SLMS) of the Indonesian National Forest Monitoring System (NFMS).

The results of both reports will then be recorded in the National Registry System (SRN) for Climate actions of Indonesia.

2.2 Planning principles

For planning the NFI in Indonesia the guidelines for National Forest Monitoring (FAO 2017) and the respective principles were considered (table 2). These principles are intended to guide the design process of national forest monitoring approaches in countries including for NFIs. The principles are divided in five main categories, namely: (1) governance principles, (2) scope principles, (3) design principles, (4) data principles and (5) overall principles.

12 MINISTER OF ENVIRONMENT AND FORESTRY DECREE NUMBER : 168/Menlhk/PKTL/PLA.1/2/2022 DATED : 24 February 2022

13 (1) non-concession production forests (non-concession HP), (2) convertible production forest (HPK-HP), (3) industrial forest (KPHP-HTI), (4) forest with concession rights (KPHP-HPH), (5) ecosystem restoration forest (KPHP-RE), (6) protection forest non-community or social forestry (HL non PIAPS), (7) conservation, (8) protection forest under community forestry (PHL-PIAPS), (9) social forestry area (KPHP-PIAPS), (10) Peatland, (11) peat and mangrove restoration (BRGM), (12) local government forest areas without cultivation rights (non-HGU-PEMDA), and (13) local government forest areas with cultivation rights (HGU-PEMDA).

14 (1) Deforestation (mineral soils and peatland), (2) concession degradations, (3) plantation forests, (4) sustainable forest management (enhanced natural regeneration, reduced impact logging), (5) enhancement of forest carbon stocks (rotational and non-rotational), (6) peatland management (water management, restoration), and (7) high conservation.

Table 2 Principles for designing a national forest monitoring system

No	Category	Description
1	<i>Governance</i>	Country ownership and responsibility
2		Legal basis for national forest monitoring
3		National forest monitoring needs a landscape view
4		National forest monitoring should be institutionalized
5		Research infrastructure and capacity building
6	<i>Scope</i>	Participatory discussion process among stakeholder on the scope and objectives of national forest monitoring
7		The national forest monitoring system must satisfy national level information needs
8	<i>Design</i>	Integration of and consistency with existing information sources
9		Flexible approach in order to integrate emerging issues and allow for periodic revisions
10		National forest monitoring should follow a multipurpose approach
11		Feasibility including cost-efficiency
12	<i>Data</i>	Well defined data and information sharing policy
13	<i>Overall</i>	Credibility through transparency and quality
14		Collaboration at the international level

Source: FAO 2017

Other important aspects considered in planning the new NFI for Indonesia were the experiences from former NFI and NFM systems developed with FAO assistance, especially recent large area forest inventories in the South East Asia region (e.g. Myanmar and Bangladesh) and experiences derived from the old NFI in Indonesia (see also chapter 2.1.1). In this context, the following came into consideration:

- Proposed technical approaches and design elements should not be too complex (referring especially to general design, sampling strategies and field plot design¹⁵)
- Expected outputs should not be too ambitious and be adapted to the scale an NFI can efficiently and reliably provide data for
- Number of attributes to be included in data collection, especially field data collection, should be consistent with measurement and data analysis capacities of the country
- Scope and scale of the NFI should be consistent with the time frame and expected resources (financial, human, technical) for implementation;
- Long term sustainability in institutional and financial terms should be built into early stages of the planning and design of the NFI.

¹⁵ The field plot design of the old NFI was very complex, time consuming and expensive and was in the past for those reasons often not fully implemented.

2.3 Objectives and purposes of the Indonesian NFI

2.3.1 Expected design features of the new Indonesian NFI

From numerous discussions with stakeholders, national forestry experts and the main government institution in charge of designing and implementing the NFI (KLHK-IPSDH) the following design features were defined for the NFI:

- Consistent grid of cluster sample plot locations and spatial distribution nationally and by major island (Java, Bali-Nusa, Kalimantan, Sumatra, Sulawesi, Maluku, Papua)
- Systematic design covering all land with forests and tree cover
- Ability of integrating the NFI grid system with sample plot grids for sub-national large area forest inventories (e.g. provinces, large watershed areas)
- Standard reporting cycle of every 5 years
- Annualized panel design for five years in the implementation (inter-penetrating panels)
- Simplified field plot design different for two major groups of land with tree cover (1) dryland, swamp, plantation forests and TOF, and (2) mangroves
- Simplified stratification with three strata (1) dryland, swamp and plantation forests, (2) trees outside forests (TOF) and (3) mangrove forests
- Sampling approach without replacement (all clusters and all plots within the clusters are permanent)

2.3.2 Objectives of the Indonesian NFI

In accordance with the identification of the (prioritized) information needs (see chapter 2.1), and the required features the new Indonesian NFI is expected to have, the following specific objectives can be formulated:

- Generate reliable estimates for key variables (e.g. tree volume, biomass, C-stock, tree species diversity) at large scale (national, by island, by land classes) for all three forest ownership categories (state, community and private forests)
- Generate estimates with known uncertainties for emission and removal factors (EF/RF) for four carbon pools (above ground, below ground, lying dead wood and litter)¹⁶ on land categories and reporting units relevant for the implementation of the FOLU net sink 2030 operational plan and the monitoring of achievements of NDC-FOLU targets (see chapter 2.1.2.2)
- Include all land areas with forests (natural forests and forest plantations), other wooded land, and other land with tree cover (trees outside forests) into the sampling frame
- Develop reliable estimates for key variables (e.g. area, volume, biomass and carbon density) with precision levels/ error margins in line with national and international reporting and monitoring requirements (e.g. UNFCCC-REDD+ reporting, reporting on results-based payments, RBP)
- Ability to generate information on the state of the forests and tree resources as well as forest dynamics and changes over time
- Credibility of NFI approaches and outputs with users and stakeholders at national and international levels (including donors for climate finance)

¹⁶ Soil organic carbon (SOC) at this stage of NFI planning not included. However, in the future SOC sampling can easily be integrated in field data collection and SOC analysis with methodologies readily available through experiences from other countries in the region (e.g. Myanmar or Bangladesh).

2.4 Sampling design

2.4.1 Sample size calculations and stratification

A draft sampling design proposal for the new Indonesian NFI considering the planning principles, the expected features and objectives from chapters 2.1 and 2.2 was developed in 2023 and documented in the report of two FAO international consultants contracted for this purpose (Tokola and Vesa 2023).

Following the analysis with data sets on variability distribution from the old NFI (basal area data¹⁷) and global data sets for height and AGB maps over Indonesia (e.g. global canopy height map for 2020 from ETH Zürich¹⁸, GEDI AGB data from 2019, 2020¹⁹, among others) the draft proposal included the following:

Table 3 First draft proposal sample sizes for Indonesian NFI

Strata	Island	Grid spacing	Sample size	E% BA at island scale
Dryland and swamp forests	Java	5 km	620	5
	Bali Nusa	5 km	506	5
	Kalimantan	20 km	443	5
	Maluku	10 km	249	5
	Papua	25 km	287	5
	Sulawesi	10 km	516	5
	Sumatra	10 km	416	5
Mangrove	All	Not defined	210	Not defined
Trees outside forests	All	Not defined	210	Not defined
Total			3457	< 5
Inaccessible areas	All	Remote sensing with separate ground truthing		
Other land areas	All	No specifics		

Source: Tokola and Vesa 2023

The number of clusters would be candidate cluster locations for which then a second sampling for separating cluster locations with forest and tree cover from cluster location with other land cover classes (without trees) would have to be carried out in order to define the final number of cluster and plot locations for field measurement (double sampling for stratification).

The consultants made proposals also for a new cluster and plot design (see chapter 2.3.2.4) and recommendations for (1) refinement of old maps and statistics, (2) development of biometric models, (3) development of rapid change monitoring procedures, and (4) development of an NFI information system.

Following these initial sample size calculations, the next step in the analysis, independent from the analysis summarized in table 3, was an assessment of sample sizes and sample (cluster) plot location based on variability distribution of area and area change proportions (forest vs non-forest) with visual interpretation of land cover types through the Collect Earth tool²⁰.

¹⁷ As mentioned in chapter 2.1.1 most likely from PSP plots within the old NFI clusters only

¹⁸ Lang *et al.* 2022

¹⁹ Potapov *et al.* 2020

²⁰ <https://openforis.org/solutions/collect-earth/>

Initial sample locations were selected from the global hexagon grid ISEA3H²¹ with 9894 plot locations over all islands of Indonesia and visually interpreted during a 5-day workshop with 40 participants in November 2023. The resulting number of clusters were then further filtered with information layers for travel time and other restriction and accessibility criteria. The final selection of centre point locations of the clusters was then carried out using a space filling curve (SFC) algorithm²² over the hexagon centroids in order to identify and geolocate those which complied with specified criteria. The details of the procedure are described in Sola (2023)²³.

The results of this exercise are summarized in table 4.

Table 4 Results of phase 1 sampling

Strata	Island	Grid spacing	Sample size	E% for area proportions at island scale
Dryland and swamp forests	Java	11 km	148	10
	Bali Nusa	11 km	119	10
	Kalimantan	18 km	413	5
	Maluku	11 km	219	5
	Papua	18 km	257	5
	Sulawesi	11 km	486	5
	Sumatra	18 km	386	5
Sub-total			2028	
Mangrove	All	Not defined	192	??
Trees outside forests	All	Not defined	490	??
Total			2710	

Source: Sola 2023

However, this second sample size proposal is optimized for area and area change assessment not for variability of the key variable of the NFI (forest above ground biomass).

The calculation procedure for this approach is also heavily based on extensive knowledge for using different R scripts for most stages of the process. The required capacities don't exist yet in the main government institution in charge of NFI implementation (IPSDH).

In addition, as in the Collect Earth (CE) exercise mentioned above, a 1 ha size square interpretation window was used overlaid over the centre point of a 40 ha hexagon. The land classification from this assessment is actually only valid for the centre plot (plot 1) of the future L-shaped NFI cluster as plot 2 and plot 3 would be located either fully outside of the interpretation window (for dryland, swamp, plantation forest) or sitting on the fringes of the interpretation window with half of the respective plot areas outside (mangrove forests and TOF). The consequence of this is that the results from the CE assessment are only valid for one out of three plots within the clusters (see figure 1).

21 <http://webpages.sou.edu/~sahrk/dgg/isea.old/tables/isea3htbl.html>

22 Space-filling curves are used in mathematical analysis for reducing higher dimensional proximity problems to a one-dimensional problem. There are different recursive geometric constructions for space-filling curves for different problem solution tasks. In our case, a discrete space filling curve for indexing grid cells were used for processing and organizing raster data (data in a spatial grid, i.e. centre point locations of the hexagons).

23 Sola, G. 2023. Annex to NFI design plan for Indonesian forests. Optimal sampling grid for NFI phase 1 visual interpretation. Consultancy report. 23 pp.



Figure 1 Overlay of dryland forest NFI cluster over a 1 ha interpretation window of Collect Earth

Following the discussions with government representatives (IPSDH), national experts and stakeholders during the first months of 2024 another additional sample size calculation exercise including differential spatial sample distribution over national, island and all the seven government recognised land classes with forests and for the four land classes where TOF can be expected (see chapter 2.1.2.1) was carried out. This actually started originally out because in both of the former analyses (table 3 and table 4) mangrove forests were not properly covered but then in the process extended to all other land classes with forests and tree cover too.

For this third calculation exercise, the NFI planning team went back to the Tokola and Vesa proposal (table 3) and initial sample size calculations based on AGB and basal area variabilities by island and for the prospective three main strata (1) dry land, swamp, plantation forest, (2) TOF, and (3) mangrove forests. The AGB data of the dry land, swamp, plantation, and mangrove forests were obtained from the old NFI provided by IPSDH, while the basal area data of TOF were obtained from a community forest inventory that was analyzed by Tiriyana (2023) (annex 5.1). From the resulting sample sizes, the nearest 5 km multiplier was used for grid spacing and the corresponding hexagon centroids were overlaid over the land areas on the islands. The initial numbers of samples following this calculation are summarised in table 5.

Table 5 Initial results sample size calculations with IPSDH

Strata	Island	Grid spacing in km	Sample size	E% for AGB at island scale
Dryland, swamp and plantation forests	Java	10	317	10
	Bali Nusa	10	306	10
	Kalimantan	20	784	5
	Maluku	10	561	5
	Papua	25	422	5
	Sulawesi	10	1048	5
	Sumatra	15	685	5
Sub-total			4124	< 5
Mangrove forests	Java	2.5	83	10 - 15
	Bali Nusa	2.5	67	
	Kalimantan	5	263	
	Maluku	7.5	56	
	Papua	15	79	
	Sulawesi	2.5	285	
	Sumatra	7.5	124	
Sub-total			956	< 5
Trees outside forests	Java	25	82	15
	Bali Nusa	20	71	15
	Kalimantan	45	84	15
	Maluku	20	66	15
	Papua	25	68	15
	Sulawesi	30	77	15
	Sumatra	45	92	15
Sub-total			540	> 5
Total			5620	< 5

The amount of samples were then subjected to an GIS based plot analysis with iterative filtering using global and national spatial layers such as Hansen Global Forest Change v1.11 (2000 – 2023), NASA SRTM digital elevation data (elevation/altitude: ≤ 2000 m above sea level), recent national forest cover layer with $\geq 82\%$ of tree cover, and the same friction layers for travel time and accessibility restrictions used in the plot analysis for the stage 2 sampling as expressed in table 4.

Sample sizes for actual field measurements were then reduced to the amount which is possible to cover with the available budget in the government over a five-year period (ca 3500) plus spare samples (ca 500) which can be mobilized to the extent needed when primary sample locations get lost over time or are deemed operationally inaccessible. The final numbers of samples (clusters) are summarized in table 6.

Table 6 Final sample size calculation (number of clusters) after iterative plot analysis

Island	Strata						Total	
	Dryland forest, swamp, plantation forest		Mangrove forest		Trees outside forest			
	Target	Spare	Target	Spare	Target	Spare	Target	Spare
Java	198	30	74	11	87	1	359	42
Bali Nusa	171	26	37	6	71	2	279	34
Kalimantan	454	68	155	23	86	0	695	91
Maluku	376	56	46	7	66	5	488	68
Papua	329	49	51	8	42	32	422	89
Sulawesi	431	67	154	23	71	2	656	92
Sumatra	553	83	86	13	94	0	733	96
Total	2512	379	603	91	517	42	3632	512
	2891		694		559		4144	

2.4.2 Sampling strategy

2.4.2.1 Rationale for the distribution of sample plots over the sampling frame

The sampling approach for the new Indonesian NFI, following McRoberts *et al.* (2015) will be:

“stratified systematic aligned sampling”

The new NFI will have three strata, namely (1) dryland forest, swamp forest, forest plantations, (2) trees outside forests and (3) mangrove forests,

The clusters will be systematically distributed over the sampling frame with hexagon-based grid spacings, which are different by strata and islands according to different sample size and precision requirements adapted to the time frame and budget the government of Indonesia is prepared to invest in the NFI.

The centre point locations of the clusters are aligned, which means they coincide with the centroids of the hexagons (no random distribution of cluster locations within the hexagon areas).

In addition, the Indonesian NFI will be implement with a panel approach over a five-year period. For the latter, the cluster numbers will be divided into 5 yearly panels of cluster locations distributed over the whole national level sampling frame (see chapter 3.2).

The new Indonesian NFI is conceptualised as continuous forest inventory (CFI) with a 5-year remeasurement cycle and permanent location of sampling units (PSPs). The use of permanent sampling units allows for estimating not only current values and net change of population parameters, but also for gaining insights into the components of change (Poso 2009).

Although in principle sampling without replacement is carried out, there will be a replacement component through the spare sampling units so that potential changes at the population level (e.g. forest cover changes, emerging accessibility issues for certain areas) can be dealt with through abandoning old sample units and replacing them with new sample units from the list of spare sampling locations (see table 6).

2.4.2.2 Hexagon based sampling frame and systematic cluster plot distribution

The hexagon-based tessellation of land areas for the Indonesian NFI (figure 2) was preferred over a square grid because of the following reasons:

- it adapts better to irregular shaped land areas, as most forest areas are, and reduces sampling bias from edge effects of the grid shape (lower perimeter to area ratio) while still maintaining a continuous grid
- developing consistent subdivisions within the hexagon frame is easier to be performed and can be done where required for subnational sampling grid purposes (e.g. province level forest inventories)

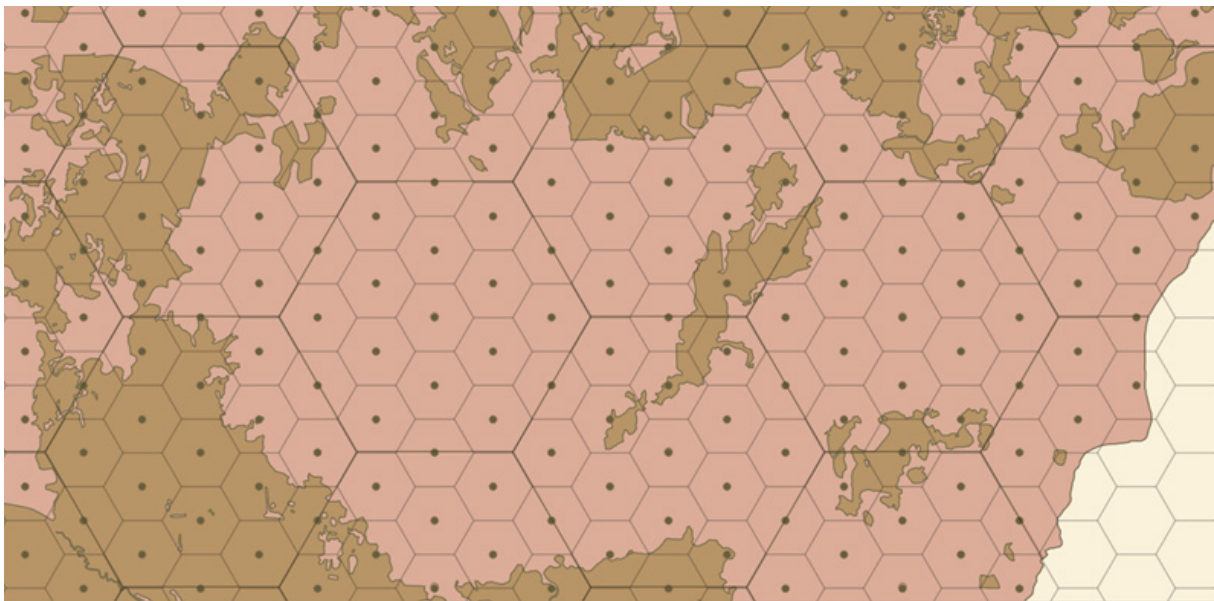


Figure 2 Geometry of the hexagon-based sampling frame of the Indonesian NFI

Figure 2 shows the integration of a 20 km hexagon-based grid of NFI cluster locations with potential subnational grid spacing of 5 km in Kalimantan. Every NFI cluster centre point location at the centroid of the 20 km hexagon is also a cluster centre point location within a sub-national 5 km grid.

2.4.2.3 Field plot design

The study of Tokola and Vesa (2023) developed also proposals for a more efficient cluster and plot design which is comparatively easy to implement operationally while fulfilling sampling theoretical requirements. Based on data from the PSPs of the old NFI, the consultants simulated different plot and sub-plot sizes as well as plot numbers within the clusters and different spatial distances between plots within a cluster and assessed the alternatives against inclusion probability of relevant tree dimensions (dbh classes), reduction of intra-cluster spatial autocorrelation and the effects on the variances of the key variable (basal area as substitute for AGB) as well as operational criteria (difficulties of movement between plots within a cluster for certain forest types, especially mangroves).

In addition, an analysis for cluster and plot design for trees outside forests (TOF) was carried out (Tiryana 2023). The outcome of this analysis indicated that the plot distance geometry within the clusters of TOF should be different (smaller) than for dryland, swamp and plantation forests. It was decided therefore to use a 50 m distance between plots rather than 100 m.

The schematic cluster design proposal is demonstrated in figure 3.

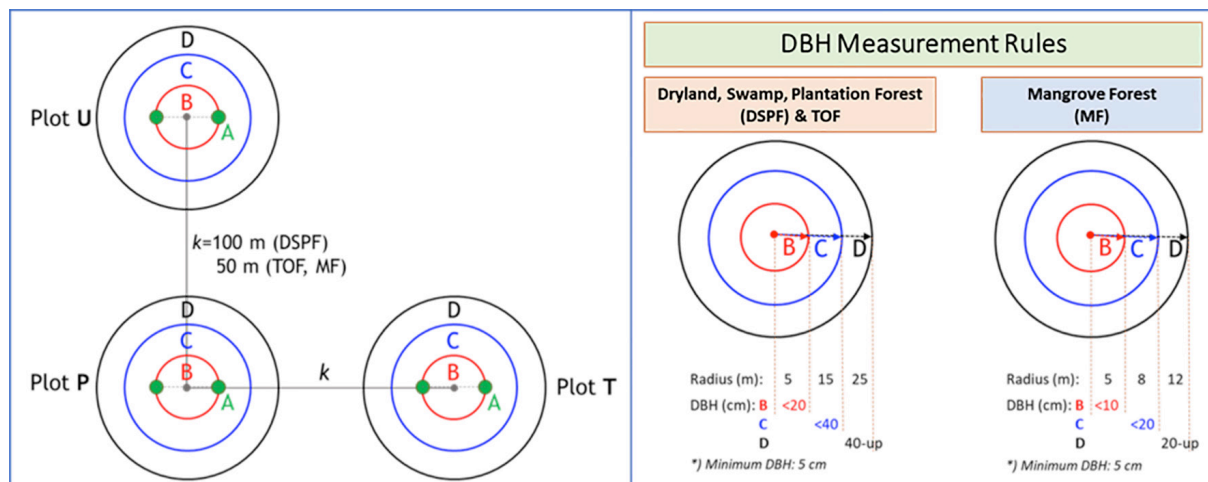


Figure 3 Cluster design of field plots for the new Indonesian national forest inventory

The cluster design is L shaped with three plots and three concentric subplots within each plot (B, C, D). Each subplot corresponds to a specific dbh class.

For stratum 1 (dryland, swamp and plantation forests) and 2 (trees outside forests) on subplot B trees with a dbh of $5 < 20$ cm o.b. are measured, while subplot C and D correspond to dbh class 20 to < 40 cm o.b. and dbh class ≥ 40 cm o.b. For stratum 3 (mangrove forests) the corresponding dbh classes are: $5 < 10$ cm o.b., $10 < 20$ cm o.b., and ≥ 20 cm.

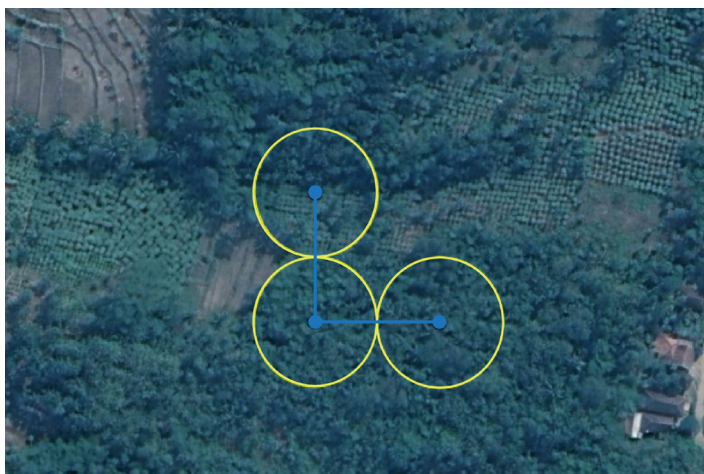
In addition, two small 1 m radius plots (subplots A1, A2) are installed on the fringes of subplot B for observation of natural regeneration and potentially other variables (litter, duff, soil and sediment variables).

The final cluster and plot design is therefore different by strata (figures 4).



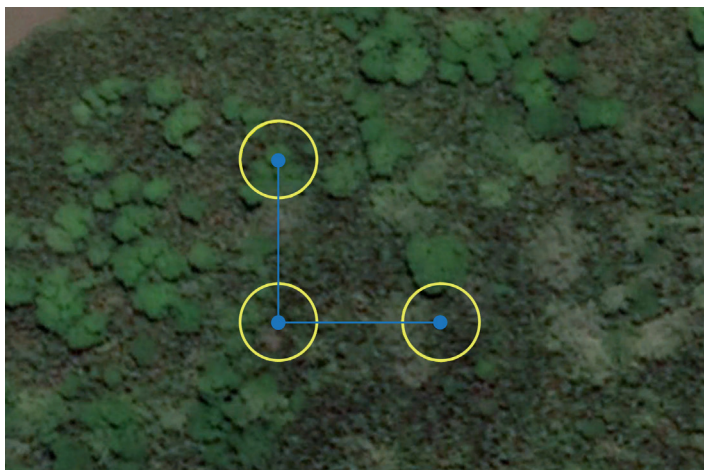
Dryland, swamp, plantation forest

$k = 100 \text{ m}$, $r_D = 25 \text{ m}$



Trees outside forests

$k = 50 \text{ m}$, $r_D = 25 \text{ m}$



Mangrove forest:

$k = 50 \text{ m}$, $r_D = 12 \text{ m}$

Figure 4 Cluster design of field plots for all three strata of the new Indonesian NFI

2.4.2.4 Methodology for field data collection

The data to be collected in the field are divided into 11 forms and cover data on cluster information, plot information, regeneration, understorey, standing trees (living and dead), stumps, lying dead wood, rattan/lianas, bamboo and potentially soil variables too, including duff and litter.

Figure 5 gives an overview on the data to be collected for each cluster, plot and sub-plots.

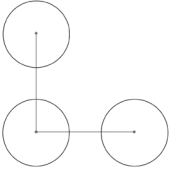
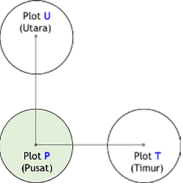
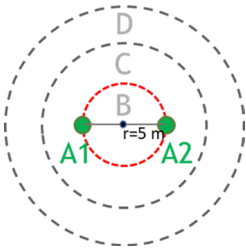
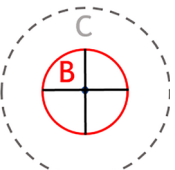
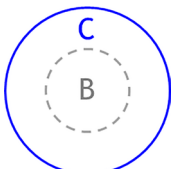
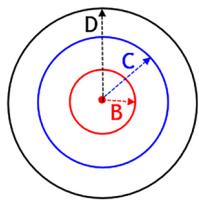
Location		Observation and measurement	Field form
Cluster		Cluster information: - Cluster number, location, and type; - Survey team; Survey timing; Accessibility	F1
Plot		Plot information: Plot number and location; Time of measurement; Accessibility; Elevation and slope; Photograph of plot condition; Land cover class; Forest type; Land use; Manager; Stand condition; Indication of human disturbance	F2
Subplot A		Regeneration: Species and number of individuals	F3
		Undergrowth: Total and sample fresh weights	F4
		Litter: Total and sample fresh weights	F5
		Soil carbon: Soil type; Depth; Sample volume	F6
Transect in subplot B		Dead wood: Diameter; Decay class	F7
Subplot C		Rattan/liana and bamboo: Species; Diameter; Length; Number of stems	F8
		Palms: Type; Species; Diameter; Height	F9
Subplot B+C+D		Trees (living and dead): DBH; DBH height; Distance; Azimuth; Species code; Species (local/scientific name); Status; Wood quality; Specific gravity class; Crown base height; Total height; Photograph or herbarium (for unknown species)	F10
Cluster		The identity of survey team: Name; Position; Mobile phone; Email	F11

Figure 5 Overview field data and observable variables to be collected for the Indonesian NFI

Source: IPSDH 2023

Further details of the field data collection methodology can be found in the Technical Guideline for the National Forest Inventory²⁴ (IPSDH 2023).

2.5 Estimation design

2.5.1 Expected outputs

The statistical estimation procedures need to be consistent with the sampling and plot design for an NFI (FAO 2017). Developing appropriate estimators and checking the applicability to the NFI approach is therefore an important aspect of the planning stage of any NFI.

Initial reporting units for the Indonesian NFI are defined as: (1) national, (2) by major island, (3) 7 land cover classes with forest cover and 4 land classes with partial tree cover (chapter 2.1.2.1) and 13 land areas corresponding to the management types for which FOLU net sink 2030 targets have been formulated (chapter 2.1.2.2).

Other reporting units or areas of interest for which data and results could be developed may be at the scale of provinces or other large areas (e.g. water catchment areas, protected areas, etc.). They can also be defined later or be adapted and modified following emerging reporting needs.

Estimations will primarily be derived from field data and complemented with remote sensing data, for instance, for post-stratification relevant for reporting areas for which no agreed maps exist yet (e.g. private and community forest areas).

Basic elements of the estimation design will be:

- Stratum s : For (1) dryland, swamp and plantation forest, (2) trees outside forests and (3) mangroves for which the area A_s is known
- Land class l : refers to strata division according to cluster and plot level data records on land class or management type areas type (see above and chapter 2.1.2)
- Tree class g : tree-level classifications based on information from tree data²⁵ in the Collect mobile forms, such as species or diameter classes or other variables of interest (e.g. stump diameters, height, etc.)

2.5.2 Area related estimates and ratio estimators

The estimator for area calculation for land classes within strata is:

$$A_{sl} = A_s \frac{\sum_{i \in snl} a_i}{\sum_{i \in s} a_i},$$

Where:

- a_i = share of the plot areas of land class at cluster level²⁶
- A_s = known total area of stratum s
- $\sum_{i \in snl} a_i$ = sum over all sampled clusters within stratum s that were assigned to land class l
- $\sum_{i \in s} a_i$ = sum over all sample plots and clusters within stratum s

²⁵ Or other lifeforms (bamboo, rattan) from which data are collected

²⁶ Plot areas within the cluster need to be aggregated at cluster level first, before further calculation since the basic unit of sampling is the cluster not the plot!

The ratio of $\frac{\sum_{i \in s \cap l} a_i}{\sum_{i \in s} a_i}$ can also be written as the proportion P_{sl} of all cluster areas of land class l in

stratum s to the sum of areas of all clusters in stratum s . The area estimator then is:

$$A_{sl} = A_s P_{sl}$$

The estimators for ratios-of-means per area unit and totals per tree class and land class within strata such as the mean value M of a variable of interest per area unit (e.g. basal area, bole volume, biomass, carbon stock) over tree class g and land class l within stratum s can be estimated by:

$$M_{slg} = \frac{1}{n_{sl}} \sum_{j \in s \cap l \cap g} \frac{v_j}{b_j}$$

Where:

- n_{sl} = number of clusters in land class l within stratum s
- b_j = area of the clusters (aggregated plot or sub-plot areas by dbh class)
- v_j = measure of variable of tree j (e.g. basal area, bole volume, biomass)

For estimating the total value T of a variable v over tree class g and land class l within stratum s the following equation applies:

$$T_{slg} = M_{slg} A_{sl}$$

For aggregating estimates across strata, the following equations will be used:

Areas and totals will be aggregated first with:

$$A_l = \sum_s A_{sl}$$

$$T_{lg} = \sum_s T_{slg}$$

And then the proportions P and mean values M per area unit in the reporting unit calculated with:

$$P_l = \frac{A_l}{\sum_s A_s}$$

$$M_{lg} = \frac{T_{lg}}{A_l}$$

2.5.3 Estimates at the tree level

From the NFI estimation design for the means for tree level variables²⁷ such as diameter (dbh), volume, biomass, height or C-content, of class g trees in land class l would be estimated with:

$$D_{lg} = \frac{\sum_{j \in l \cap g} w_j d_j}{\sum_{j \in l \cap g} w_j}$$

Where:

- D_{lg} = stands for any mean value of a variable by land class as required for calculations
- w_j = weight of the tree j with $\frac{1}{a_j}$
- a_j = the sub-plot area of the respective dbh class from which tree j is measured
- d_j = diameter (dbh) of tree j (or another variable)
- g = here dbh class which corresponds to the three subplot areas ($r=5$ m, 15 m, 25 m for clusters in strata 1 and 2; $r=5$ m, 8 m, 12 m for clusters in stratum 3), but can also acquire classes from other lifeforms measured (e.g. natural regeneration, deadwood, bamboo, rattan).

For arriving at the per ha means for the estimate of tree level biomass the following equation can also be used:

$$\hat{Y}_{ha^{-1}} = \sum_{i=1}^Z \{ \bar{y}_{j \in l \cap g_z} * n_{g_z} ha^{-1} \}$$

Where:

- $\hat{Y}_{ha^{-1}}$ unbiased estimator of the mean tree level biomass per area unit (ha)
- $j \in l \cap g_z$ mean biomass of trees j in land class l of stratum s in dbh class g_z
- g_z represents the tree classes, here the 3 dbh classes with 3 different subplot areas by strata: strata 1 and 2 ($z=1$ with $a_1 = 0.007854$ ha, $z=2$ with $a_2 = 0.070686$ ha, and $z=3$ with $a_3 = 0.196350$ ha); and stratum 3 ($z=1$ with $a_1 = 0.007854$ ha, $z=2$ with $a_2 = 0.020106$ ha, and $z=3$ with $a_3 = 0.045239$ ha)
- n_{g_z} number of trees in dbh class g_z

In this equation the weighting is integrated in:

$$n_{g_z} ha^{-1} = \frac{n_z}{\sum_{i=1}^m a_z}$$

Where:

- m total number of (sub)plots in tree class g_z
- a_z area of subplots of tree class g_z in ha

²⁷ Correspondingly for bamboo, rattan, lianas, palm trees also

An analogous weighting is performed for bamboo, rattan and lianas but with one tree class and one subplot area only ($r = 15\text{m}$; $z=2$ with $a_2 = 0.070686 \text{ ha}$).

For ratio estimates of biomass and carbon stock per ha at the cluster level the following equation can be used:

$$Y_k \text{ ha}^{-1} = [W_{jg1} * \sum_{j=1}^i y_{j \in lsng1}] + [W_{jg2} * \sum_{j=1}^i y_{j \in lsng2}] + [W_{jg3} * \sum_{j=1}^i y_{j \in lsng3}]$$

Where:

$Y_k \text{ ha}^{-1}$ per ha ratio of total living biomass (AGB, BGB) at the level of clusters

k number of the respective cluster

$y_{j \in lsng_z}$ biomass of tree j in land class l of stratum s and tree class g_z ($z=1-3$)

W_{jg1-3} weighting factor according to tree class areas within a cluster

$$\left\{ \frac{1}{\sum_{m=1}^3 a_{g_z}} \right\}$$

The mean biomass and C-stock per ha estimator can also be calculated from the sum of the cluster level weighted per ha values divided by the number of clusters.

$$\hat{Y}_{\text{ha}^{-1}} = \frac{1}{n} \sum_{i=1}^n Y_k \text{ ha}^{-1}$$

The descriptive statistics (standard error, standard deviation, variance, confidence interval, range and coefficients of variation) are calculated for the variability of target variables (e.g. biomass and carbon stock) at the cluster level with a 5% error probability (95% confidence level).

2.5.4 Estimates for other population parameters

2.5.4.1 Lying coarse deadwood (CDW)

The Indonesian NFI will use the line intersect method (LIS) for sampling coarse lying deadwood (Marshall *et al.* 2003). For calculating surface area of the plot area covered by CWD and ultimately volume and biomass per area unit, there are basically two approaches: (1) direct measurement of the transect length in cm over the deadwood piece or (2) by measuring the diameter of the deadwood pieces which intersect with the intersect line at the mid-point of the CDW piece²⁸ and the tilt angle of the deadwood log to the intersect line as the deviation from the horizontal (figure 6). The Indonesian NFI uses the second approach.

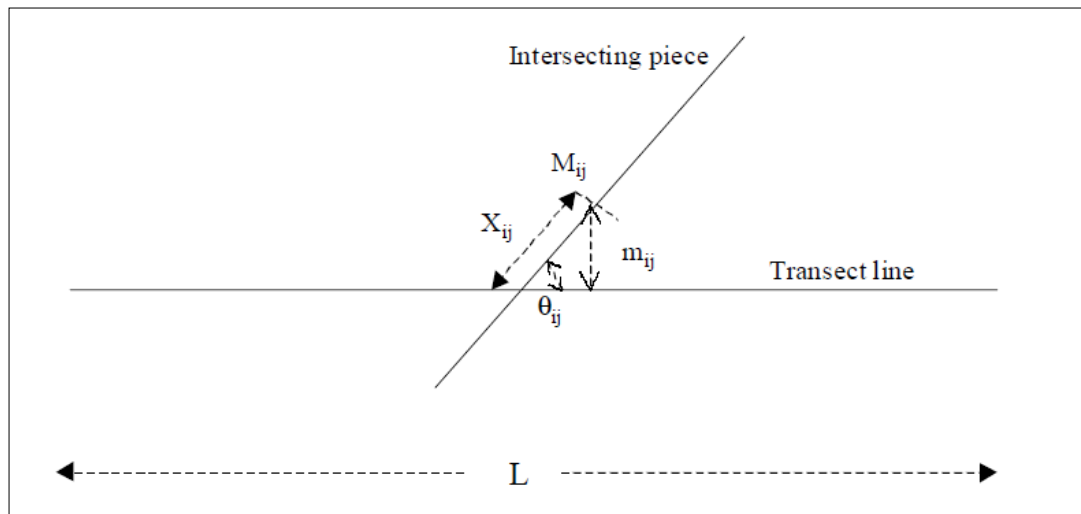


Figure 6 Intersection length and tilt angle in CDW measurements

Source: Marshall *et al.* 2000

The parameter of interest is the volume of deadwood in m³ per area unit (plot area or per ha). The calculation for CDW volume, considering all the assumption as described in Marshall et al. 2000 are

$$v_{cdw_i} = \frac{\pi^2 A}{800000 L} \times \sum_{j=1}^{m_i} \frac{d_{ij}^2}{\cos(\alpha_{ij})}$$

Where:

v_{cdw_i} = volume of CDW of an individual line sect in m³

A = area unit (area unit in m², for 1 ha = 10000)

L = length of line intersect in m ($L = 5$ m with four transects per plot)

i = individual line intersect

j = individual pieces of CDW

d_{ij} = diameter of the CDW piece at the point of intersection/ midpoint (m_i) of the log in cm

α_{ij} = tilt angle of individual CDW pieces from horizontal to the intersection line

If the tilt angles found in the field are small, the values of $\cos \alpha$ approach 1 and the equation can be further simplified by ignoring the angle.

²⁸ Not at the point of intersection, unless it is assumed that at average all CDW pieces intersect at their midpoint (see below).

For converting the deadwood volume into biomass and carbon stocks per area unit, the degree of decay of the wood needs to be considered. Specific decay reduction factors (DRF) for the tropics do not exist as yet. For conversion of CDW volume into biomass the following DRFs from temperate forests will be used (table 7). The wood density of CDW pieces will then be reduced according to the degree of decay (grade 1 – 3) as identified in the field.

Table 7 Decay classes and reduction factors for wood density in lying CDW

Decay class	Decay reduction factor (DRF)
Grade 1	1.15
Grade 2	1.35
Grade 3	1.65

Based on Russel *et al.* (2015)

2.5.4.2 Organic carbon content in soils and sediments

One important population parameter which has been excluded so far from the NFI approach in Indonesia, because of lack of funding, is the organic carbon content (SOC) in soils and sediments under forests. However, SOC is an important carbon pool especially in mangrove forest areas and should be included in the future when possible funding sources are available.

When SOC would be included into a future NFI sampling approach or in a separate soil and sediment carbon survey, the following could be considered:

The variables analysed from the soil and sediment samples are normally: (1) wet weight in g, (2) dry weight in g, (3) bulk density in Mg m⁻³, (4) organic carbon content in % of the bulk density, and (5) stoniness % (in Mangroves always zero).

In addition it is needed to have: (6) volume factors from the samples in cm³ per depth layer, (7) volume to area factors (*vaf*) by layer in m³/m² and (8) the area factor in m² for conversion to per hectare values.

The equation then for SOC per area unit looks like this²⁹:

$$SOC_a = \sum_{i=1}^n (bd_i * oc_i * sc_i * vaf_i * a)$$

Where:

- SOC_a = soil organic carbon content in Mg per area unit (ha)
- i = sediment layers which have been sampled³⁰
- n = number of layers from which samples were taken
- bd_i = bulk density of sediment in layer i in Mg per m³
- oc_i = organic carbon content factor from percentage of bulk density
- sc_i = correction factor for stoniness (in Mangroves = 1)
- vaf_i = Volume to area conversion factor (m³/m²) for layer i
- a = area factor in m² (10,000 for 1 ha)

²⁹ For peatland the equation is different (substrate and the sampling methodology is different)

³⁰ For example: 0-15, 15-30 depth in cm for dryland soils; or 0-15, 15-30 30-60, 60-90 depths in cm for mangroves or any other suitable subdivision of the soil pit.

2.5.5 Uncertainty estimates

For estimating uncertainties, it is important to consider that spatially systematic sampling is used for the Indonesian NFI. Although systematic sampling is widely used in large area forest inventory, there are certain well-known issues in assessing uncertainties in systematic sampling (e.g. Cochran 1967, Zöhrer 1980, Heikkinen 2009).

However, in practice the formulas for simple random sampling (SRS) can be applied provided the target population shows no periodicity or trends and elements of randomness are introduced, such as drawing samples with a random start (De Vries, 1986). In the case of Indonesia, it can therefore be assumed that SRS error estimators are acceptable approximations to real uncertainties³¹.

The assessment of uncertainties starts with computation of cluster level sums of the stratum specific proportions for area estimates and means for other variables (e.g. biomass, carbon stocks) for which sampling errors are needed.

The estimator for which uncertainties are calculated is:

$$\bar{y}_{ic} = \frac{\sum_{c=1}^n y_{ic}}{n}$$

Where:

y_{ic} = unit value of the target variable (land class area proportion, AGB, BGB, CDW, SOC, tree heights etc.) at the level of individual clusters

$\bar{y}_{ic}$ = mean value of the target variable of the sample

n = number of samples: (1) all clusters in the respective stratum for area proportions³², (2) all accessible clusters with trees or measured for AGB, BGB, tree heights etc.

The sampling variance is then calculated with:

$$Var_{\bar{y}_{ic}} = \frac{\sum_{c=1}^n (y_{ic} - \bar{y}_{ic})^2}{n-1}$$

The standard deviation of the means with:

$$SD_{\bar{y}_{ic}} = \sqrt{Var_{\bar{y}_{ic}}}$$

The standard error then with:

$$SE_{\bar{y}_{ic}} = \frac{SD_{\bar{y}_{ic}}}{\sqrt{n}}$$

And then sampling error percent with:

$$E\% = 100 \cdot \frac{SE_{\bar{y}_{ic}}}{\bar{y}_{ic}}$$

31 It is known that for systematic sampling in large area forest inventory calculated errors tend to overestimate the real error of variables in the target population so that with the SRS estimators responsible managers are on the safe side.

32 Including the inaccessible clusters for which only remotely sensed land cover information is available (no ground measurements)

The uncertainty of the combined per ha means of the target variables as well as the uncertainty of the combined means at the level of total areas (strata, land classes, administrative units, management type areas, etc) can be calculated with the formula for simple error propagation (IPPC 2000).

$$U_{total} = \frac{\sqrt{(u_1 \bar{y}_1)^2 + (u_2 \bar{y}_2)^2 + \dots + (u_i \bar{y}_i)^2}}{\bar{y}_1 + \bar{y}_2 + \dots + \bar{y}_i}$$

Where:

U_{total} = percentage of uncertainty in the sum of quantities

$\bar{y}_i$ = uncertain quantity of the respective target variable

u_i = percentage uncertainty (SE% or E%) associated with $\bar{y}_i$

The occurrence of non-sampling errors, especially measurement errors in the field are difficult to be quantified. However, every field crew at the level of the 22 BPKH units goes through, at least a one-week training in order to ensure full understanding of the field methodology and a proper use of the measurement instruments and data collection protocols in order to reduce the potential effect of measurement errors.

However, it can be assumed that measurement errors that occur randomly are reflected in the sampling error estimates since they increase the variances of the target variables (Cochran 1967).

2.5.6 Considerations derived from division of the sampling frame into yearly panels

The NFI planning team in Indonesia has decided to implement the NFI with a panel approach. The panel in this sense refers to a set of samples (clusters) distributed spatially over the complete area of the population of interest, i.e., at national level over all land cover included in the three strata of the Indonesian NFI³³. There would then be five yearly panels covering a proportion of the total number of samples each year from the numbers calculated in chapter 2.3.1.

When calculating the estimates for the variables at the scale of the individual (yearly) panels, the equations as described in chapters 2.4.2 – 2.4.5 can readily be applied.

However, for division of a sampling frame into yearly panels, at least the following needs to be considered:

- The sampling error for single panels will increase by the square root of the number of the panels, i.e., with five equal panels by 2.24 times (Patterson and Reams 2005). For example, where a 5% error is expected for estimates derived from all samples, this error would go up to 11% and for a 10 expected error (e.g. in mangroves at the scale of the island) it would be ca 22%³⁴;
- Travel times are increasing too, as the spatial distance between and among sample sites to be visited is roughly five times larger. To what extend this influences overall travel times operationally and the completion time of the NFI in general, cannot yet be established and should be part of intermediate evaluations as indicated in the NFI roadmap (see chapter 3.1).

³³ It is important to try to avoid spatial bias when applying a panel approach

³⁴ When sample numbers allocated to each panel are unequal then the error increase at the scale of yearly panels is also unequal.

For combining the estimates from 2 or more panels, there are in principle two different methods:

- (1) the moving average method (MA) and
- (2) the temporally indifferent method (TI)

The moving averages method (MA), when combining the panels, the estimates $\hat{Y}_p$ from each panel would have a weight w_p . This weight could be equal to every panel or the more recent panels could have a higher weight.

The estimator for combining the panels with the MA method would then be:

$$\hat{Y}_p = \sum_{p=1}^P \hat{Y}_p w_p$$

The variance for $\hat{Y}_p$ then would be

$$Var_{\hat{Y}_p} = \sum_{p=1}^P w_p^2 Var_{\hat{Y}_p}$$

Applying the MA would have then the additional issue of defining the weights.

The temporally indifferent method (TI) is easier to apply since estimates are calculated from increasingly available samples pooled together every year. With this method no weighting of panels is necessary and the calculations can be done with the same equations as describes in chapter 2.3.2 – 2.3.4. With the TI method every year when the field work is finished and the data from newly measured clusters become available, the new combined data sets are treated as if they were all from the same panel.

However, if the size of the panels is considerably different across the years of the NFI implementation cycle, then a weighting of the panels is advisable and therefore the application of the MA method instead of the TI method. The increase of expected sampling errors at the scale of yearly panels is also differential following the different amounts of samples collected for the respective panels (see chapter 3.2.2).

3 Implementation of the new National Forest Inventory

3.1 Road map for the National Forest Inventory of Indonesia

The new Indonesian NFI will be implemented in three phases: (1) Transition and Preparation Phase, (2) Implementation Phase and (3) Analysis and Evaluation Phase (figure 7). The transition and preparation phase has started in 2022 with preparatory studies and was further developed during 2023 and 2024 with a full redesign of the NFI (see chapter 2). This phase is planned to culminate by the end of 2024. In this phase all infrastructure related to regulations, systems, tools and procedures have been prepared. In addition, testing of the new design methodology, especially the field methodology, has been carried out together with academics, experts and field practitioners.

The socialisation of the new design, the relevant regulatory framework as well as training has also been done during this phase so that appropriate understanding of existing regulations as well as the required knowledge and ability to implement the NFI is acquired by stakeholders and operational implementers at the site level.

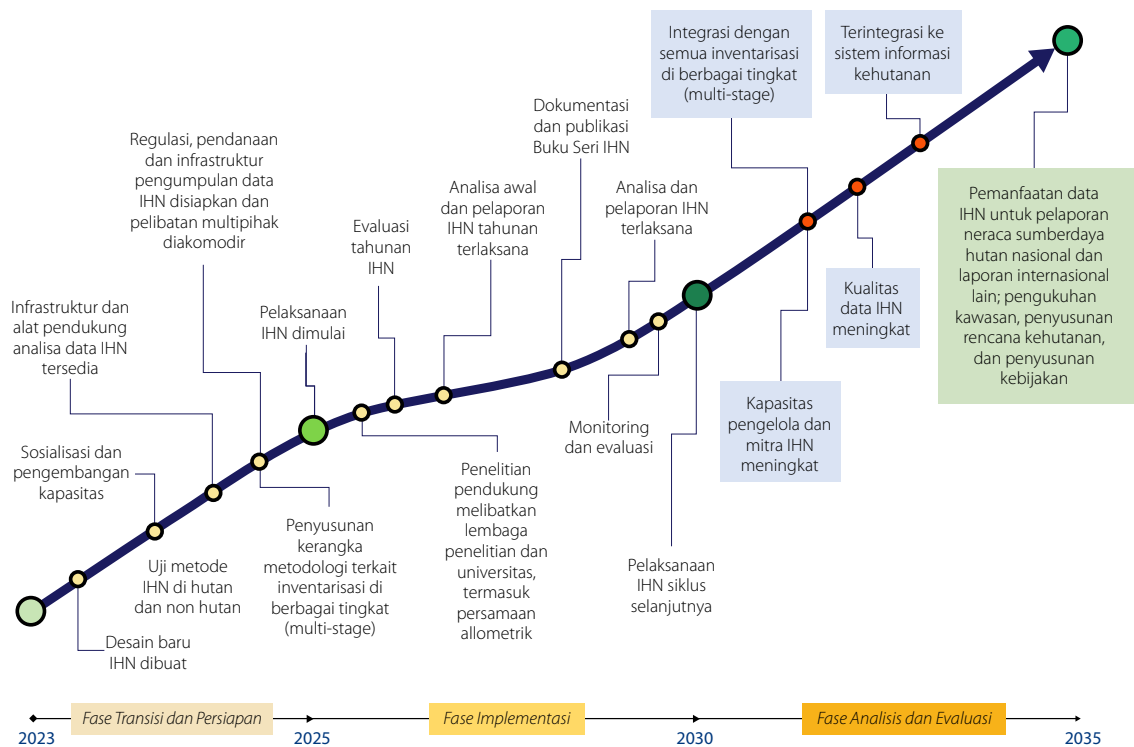


Figure 7 Implementation process of the Indonesian NFI

Source: Manuri 2024

The implementation phase of the NFI takes place over a five-year period from 2025 to 2029. Supporting research involving relevant academics and researchers will be rolled out in parallel to the implementation of the NFI. Research topics will be decided and agreed accordingly in time towards the end of phase 1 and the early stages of phase 2. During phase 2 preliminary data analysis and evaluation will be conducted to determine potential obstacles faced and solutions to resolve problems that may occur.

For implementing the NFI, a panel approach, similar to NFIs in other large countries (e.g. Peru, USA, Finland), with inter-penetrating annual panels will be applied. This means that the sample frame will be divided into five yearly groups of samples distributed over the whole of the population of interest and a proportion only of total samples collected every year to complete the full cycle of measurements after 5 years.

This approach has the advantage of reducing the annual budgetary burden for fieldwork costs by the government, although the overall costs over the whole inventory cycle may be higher. To what extent, this would have to be evaluated during and after the completion of the first cycle of the new NFI.

The implementation phase of the NFI will have three components namely:

- (1) the basic component with capacity building and establishing infrastructure that enables the implementation of the NFI,
- (2) the operational component for actual NFI implementation in the field and
- (3) the strategic component, which includes issues such as securing long term funding for a permanent NFI system and outreach to stakeholders and decision makes about the usefulness of NFI data and information

The basic component will have three sub-components such as:

- Preparation of a legal umbrella for the implementation of the NFI
- Set up of the necessary Infrastructure for field implementation, data analysis and dissemination of NFI results
- Human resource capacity development, especially for field implementation and data analysis

The operational component will have the following sub-components:

- Application and management of the panel system (see also chapter 2.4.6 and 3.2)
- Construction of a tree species data bases (presumably also for bamboo and rattan)
- Development of supporting research (e.g. evaluation of usefulness of existing allometric models, development of new models if needed)
- Development of methods for measurement of hard-to-access clusters using remote sensing techniques (e.g. options for collaborating with the GEDI project of NASA)

The strategic component will also have three sub-components:

- Engagement of Parties with target audiences in three areas: (1) field measurements, (2) research and (3) publication
- NFI dissemination and publication at national, regional and international levels
- Long term sustainability strategy (secure funding, institutionalisation of the NFI, human resource development)

The Analysis and Evaluation phase will be implemented after the fulfilment of the first full NFI cycle from 2030 onwards. Although data analysis and evaluation of several aspects of the NFI will start already during the implementation phase (e.g. annual or preliminary results), the full analysis with presenting all data and information comprehensively will be conducted in this phase.

It is also expected that in this phase, the human resources of NFI implementers have improved and institutions have been established so that conditions to run the next cycle are available. In addition to continuing the second cycle of IHN measurement, this phase also evaluates the implementation of the first cycle of IHN. Evaluation is carried out through learning from the implementation of NFI at the national, provincial and site levels. Evaluation is also carried out on other NFI support systems.

Further details of the NFI roadmap can be found in Manuri (2024) including a logframe for NFI implementation with short, medium- and long-term target outputs (2025, 2030, 2035), and corresponding performance indicators.

3.2 Division of the sampling frame into five annual panels

3.2.1 Distribution of panels and samples over islands, strata, land classes and BPKHTL units

For practical and operational reasons, the sampling frame for the Indonesian NFI will be divided into five annual panels of sample units (clusters). For the selection of predefined samples (see table 6) which have to be measured annually by the BPKH units in the field a stratified random selection will be applied. For each island and for the three strata the number of sample units to be measured each year amount to a proportion of the total number spatially distributed over the whole sampling frame.

However, the distribution by strata over the five annual panels results in larger distances between and among the clusters (at average five times larger) that are to be measured every year which adds the inconvenience of an increase in travel time and travel costs at the level of operational units for NFI implementation.

Therefore, an additional level of plot analysis is applied which allows for a kind of “clustering of the clusters” at an administrative level below the islands and provinces in order to still guarantee a high level of spatial distribution of the selected sample units at the scale of the annual panels while reducing travel time and travel costs between and among cluster locations.

The administrative subdivisions in Indonesia go from level 1 (provinces) to level 2 (regencies and cities), level 3 (districts) and level 4 (villages). Indonesia has 38 provinces, 416 regencies and 7252 districts. The level at which an aggregation of sample units across strata and panels has been carried out is the level 2 (regencies).

The procedure can be summarized in four principal steps as following:

1. Select NFI sample units by strata and allocate them randomly over the five annual panels (primary selection)
2. Visualize the selected sample units by strata and panel at the scale of the regencies on the seven island groups
3. Re-arrange the sample units within the boundaries of the regencies so that sample units (NFI clusters) are clustered for reducing travel distances between and among them
4. Aggregate the sample units across strata, regencies and island groups to generate new allocations of sample units over the five panels (secondary selection)

Step 3 is carried out by strata and across the five panels so that the primary allocation of the sample units is changed at the scale of the panel without changing the geolocation of the NFI cluster.

The number of sample units per stratum and panel does also not change, only the final allocation of sample units over the panels.

In a further step, the number of samples to be distributed over the five panels has been adapted to annual budgetary as well as capacity building and training needs and restrictions of the government institutions in charge of implementing the NFI. Following this adaptation, the number of samples were unevenly distributed over the annual panels (see table 8).

Table 8 Percentage share of samples for the five panels of the first measurement cycle

Panel number	Year of implementation	Percentage share of samples to be collected
1	2025	10
2	2026	25
3	2027	25
4	2028	25
5	2029	15

The overall distribution of the samples by island group and strata is summarized in Table 9 below. More details and the maps can be seen in annex 5.2.

Table 9 Division of the NFI sample frame into five annual panels

Island group/strata	Annual panels					Total
	1	2	3	4	5	
Bali_Nusa	30	70	66	70	43	279
Dryland, swamp, plantation forests	16	41	43	47	24	171
Mangrove forests	5	11	9	6	6	37
Trees outside forests	9	18	14	17	13	71
Jawa	52	97	87	72	51	359
Dryland, swamp, plantation forests	24	57	48	41	28	198
Mangrove forests	10	17	17	19	11	74
Trees outside forests	18	23	22	12	12	87
Kalimantan	53	162	177	191	112	695
Dryland, swamp, plantation forests	29	111	116	124	74	454
Mangrove forests	11	34	38	43	29	155
Trees outside forests	13	17	23	24	9	86
Maluku	37	123	130	120	78	488
Dryland, swamp, plantation forests	23	91	99	98	65	376
Mangrove forests	9	10	12	9	6	46
Trees outside forests	5	22	19	13	7	66
Papua	39	104	105	105	69	422
Dryland, swamp, plantation forests	24	84	83	85	53	329
Mangrove forests	5	15	14	11	6	51
Trees outside forests	10	5	8	9	10	42
Sulawesi	60	156	162	167	111	656
Dryland, swamp, plantation forests	29	104	111	113	74	431
Mangrove forests	13	34	43	39	25	154
Trees outside forests	18	18	8	15	12	71
Sumatera	94	188	173	175	103	733
Dryland, swamp, plantation forests	54	150	140	132	77	553
Mangrove forests	14	22	19	19	12	86
Trees outside forests	26	16	14	24	14	94
Grand Total	365	900	900	900	567	3632

Figure 8 shows the sample units from table 9 on the map.

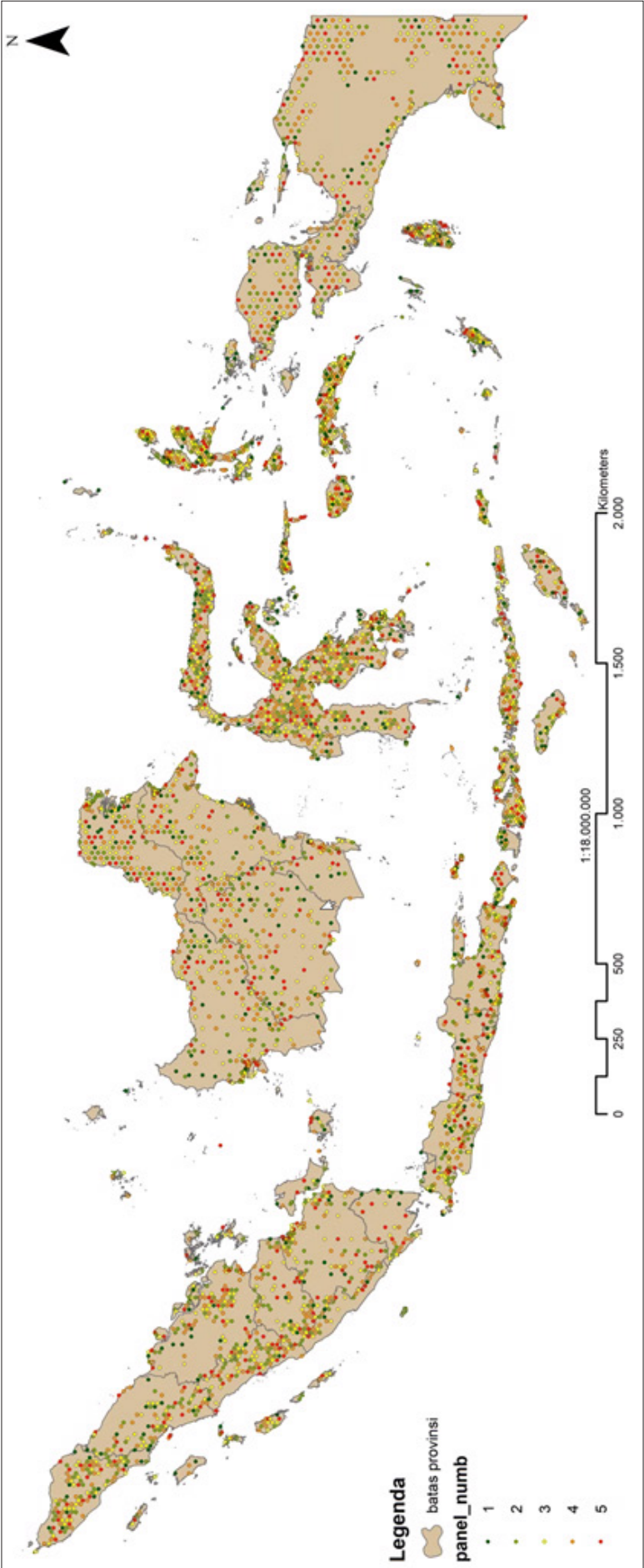


Figure 8 NFI sample units distributed over five panels at national scale

The distribution of the NFI sample units (NFI clusters) over the regional units of the Forest Administration (BPKH offices) is then to be seen in table 10.

Table 10 Distribution of NFI clusters over BPKH areas

BPKH areas and provinces	Strata			Total
	Dryland, swamp and plantation forest	Mangroves	Trees outside forest	
BPKHTL 01	158	15	21	194
Sumatera Barat	85	4	8	97
Sumatera Utara	73	11	13	97
BPKHTL 02	53	26	26	105
Sumatera Selatan	53	26	26	105
BPKHTL 03	103	31	36	170
Kalimantan Barat	103	31	36	170
BPKHTL 04	227	89	16	332
Kalimantan Timur	117	52	12	181
Kalimantan Utara	110	37	4	151
BPKHTL 05	11	23	8	42
Kalimantan Selatan	11	23	8	42
BPKHTL 06	191	34	40	265
Maluku Utara	165	13	26	204
Sulawesi Utara	26	21	14	61
BPKHTL 07	112	15	26	153
Sulawesi Barat	32	1	3	36
Sulawesi Selatan	80	14	23	117
BPKHTL 08	76	6	27	109
Bali	7	2	11	20
Nusa Tenggara Barat	69	4	16	89
BPKHTL 09	211	33	40	284
Maluku	211	33	40	284
BPKHTL 10	199	33	37	269
Papua	199	33	37	269
BPKHTL 11	198	74	87	359
Banten	16	5	10	31
Daerah Istimewa Yogyakarta	5		5	10
Jawa Barat	59	8	26	93
Jawa Tengah	47	17	16	80
Jawa Timur	71	44	30	145

BPKH areas and provinces	Strata			Total
	Dryland, swamp and plantation forest	Mangroves	Trees outside forest	
BPKHTL 12	10	6	4	20
Kepulauan Riau	10	6	4	20
BPKHTL 13	74	10	18	102
Jambi	67	1	12	80
Kepulauan Bangka Belitung	7	9	6	22
BPKHTL 14	95	31	44	170
Nusa Tenggara Timur	95	31	44	170
BPKHTL 15	37	9	2	48
Gorontalo	37	9	2	48
BPKHTL 16	169	54	18	241
Sulawesi Tengah	169	54	18	241
BPKHTL 17	130	18	5	153
Papua Barat	130	18	5	153
BPKHTL 18	114	1	7	122
Aceh	114	1	7	122
BPKHTL 19	97	25	6	128
Riau	97	25	6	128
BPKHTL 20	47	3	12	62
Bengkulu	28		3	31
Lampung	19	3	9	31
BPKHTL 21	113	12	26	151
Kalimantan Tengah	113	12	26	151
BPKHTL 22	87	55	11	153
Sulawesi Tenggara	87	55	11	153
Total	2512	603	517	3632

The distribution over the five panels by BPKHTL unit and provinces is to be seen in table 11.

Table 11 Distribution of NFI clusters over BPKH areas, provinces and annual panels Further implications from the division of sampling frame into annual panels

The uneven distribution of samples over the annual panels may require a weighting of the data sets of the individual panels when it comes to combining the data from two and more panels and also the increase of expected sampling error at the scale of the individual panels will be uneven (see chapter 2.4.6).

Table 11 gives an indication for weighting factors if the intended distribution of samples over the annual panels stays as given in table 8.

Table 11 Initial weighting factors w_i for panels of the Indonesian NFI

Year of data analysis	Combination of Panels	w_i of individual panels when combined for data analysis				
		P1	P2	P3	P4	P5
2026	P1	1				
2027	P1 + P2	0.286	0.714			
2028	P1 + P2 + P3	0.167	0.417	0.417		
2029	P1+P2+P3+P4	0.118	0.294	0.294	0.294	
2030	P1+P2+P3+P4+P5	0.100	0.250	0.250	0.250	0.150

If during the implementation of the NFI the allocation of sample units over the panels would be different from the distribution in table 8, then the weighting factors need to be adapted.

Furthermore, the expected increase of sampling errors³⁵ at the level of the individual panels at the scale of the island groups would amount to the values as expressed in table 12.

Table 12 Expected sampling error SE_{pj} for key variable AGB for individual panels at scales of islands

Stratum	SE_{p1-5} (all panels on islands)	SE_{pj}				
		P1	P2	P3	P4	P5
Dryland, swamp, plantation forest	0.05	0.16	0.10	0.10	0.10	0.13
Dryland, swamp, plantation forest (Jawa, Bali-Nusa)	0.10	0.32	0.20	0.20	0.20	0.26
Trees outside forests	0.15	0.47	0.30	0.30	0.30	0.39
Mangrove forests (Malukku, Papua)	0.10	0.32	0.20	0.20	0.20	0.26
Mangrove forests (Bali-Nusa, Java, Kalimantan, Sulawesi, Sumatra)	0.15	0.47	0.30	0.30	0.30	0.39

However, at national scale the expected error for all panels and strata and for individual annual panels would be lower (Table13).

Table 13 Expected sampling error SE_{pj} for key variable AGB for panels at national scale

Stratum	SE_{p1-5} (all panels national)	SE_{pj}				
		P1	P2	P3	P4	P5
Dryland, swamp, plantation forest	0.02	0.06	0.04	0.04	0.04	0.05
Trees outside forests	0.05	0.17	0.11	0.11	0.11	0.14
Mangrove forests	0.05	0.16	0.11	0.11	0.11	0.13
National scale (all panels combined)	0.02	0.07	0.04	0.04	0.04	0.06

35 Half-width of the confidence interval with 95% inclusion probability

3.3 Quality assurance and quality control

In order to establish a quality assurance and quality control (QA/QC) system for the NFI, the workflows especially for data collection, data processing and analysis need to be standardized through the development of standard operation procedure (SOP). The QA/QC teams can then compare the workflows as applied by the field or office teams with the standards established and define how near or how far away the actual workflows and the quality of the work is from what has been intended.

In addition, accuracy tables have to be developed where the tolerances for measurement or data recording errors for all relevant variables are defined. The QA/QC teams can then compare the actual measurements by the field crews including comprehensiveness of the measurements with the tolerances allowed. For some variables (e.g. land cover type or land class, cluster ID, etc) no tolerances should be allowed while for others (e.g. geolocation with GPS, dbh or height measurements) the tolerances need to be established.

For the quality assurance of the NFI work, three main areas need to be considered: (1) training and capacity building of NFI personnel, (2) quality control during the execution of work (both field and office work), and (3) quality control after finalization of the work.

Training and capacity building as well as quality control during the execution of the NFI work have the aim to avoid or correct errors while quality control after finalization aims at evaluating work flows and procedures with the objective of improvement for future NFI work and potentially obtain notions on the scope and extent of non-sampling errors.

3.4 Data management and data analysis

3.4.1 Software tools for data collection, uploading and storage

For most software needs for the Indonesian NFI the open source software tools of the Open Foris suite, hosted and maintained by FAO, are used (Figure 9).

Collect Earth (CE) and Collect Earth Online (CEO) have been used in the phase 1 sampling as described in chapter 2.3.1. It can be used again for updating the number and location of clusters to be visited in the field during the implementation phase of the NFI 2025 – 2029.

For the actual field data collection, the backbone of a National Forest Inventory, OF Collect and OF Collect Mobile will be used. For that purpose, a survey design is developed, based on the field methodology and the data forms identified and agreed beforehand and described in detail in the technical guidance document for NFI implementation (IPSDH 2023). The survey design is developed in the desktop version of Collect (figure 10) and then imported into the mobile version of Collect on a standard commercial PDA, such as a tablet or mobile phone (figure 11).

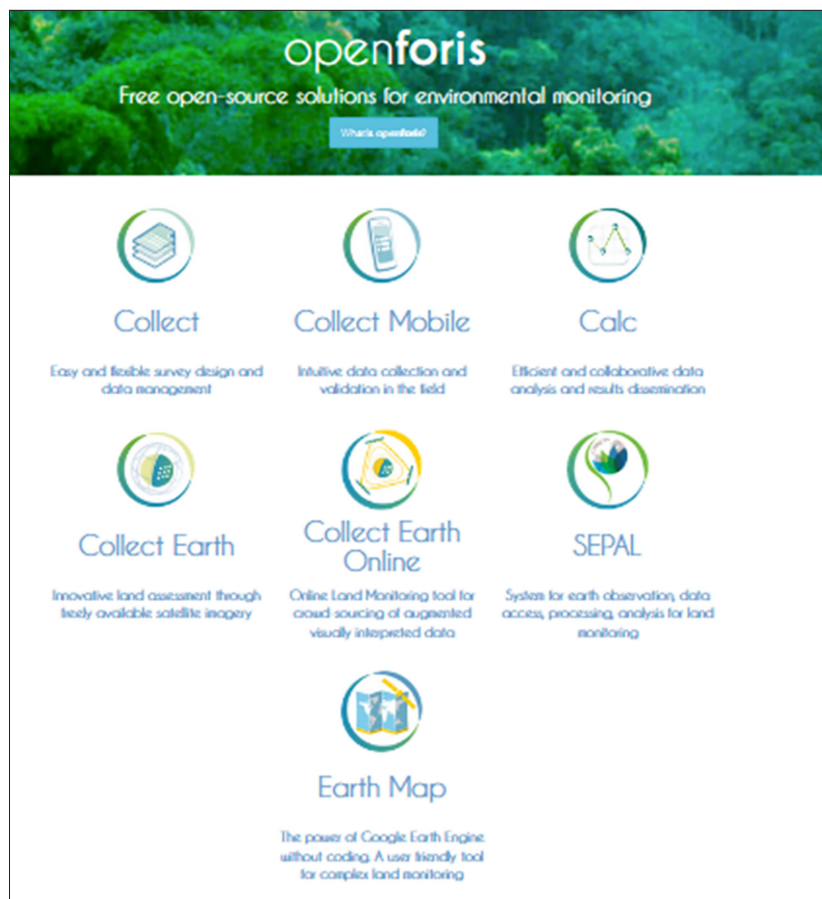


Figure 9 Open Foris software tools for forest inventory and forest monitoring

Source: <https://openforis.org/>

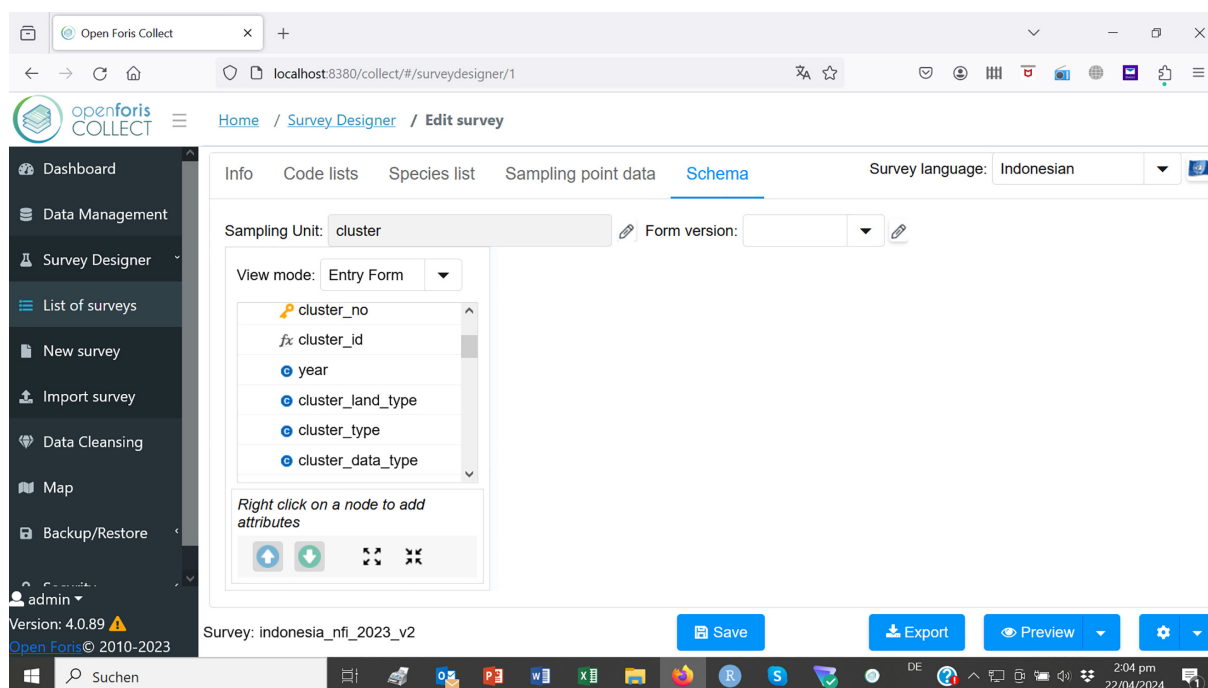


Figure 10 OF Collect Survey Designer for developing electronic field forms for data collection

Once all the data are recorded and saved on the tablet or phone, the field crew leader will upload the data sets to either a regional data base at the level of the BPKH offices or directly to a central data server at MoEF (KLHK).



Figure 11 Collect Mobile app of the Indonesian NFI on a PDA (tablet, mobile phone)

For uploading the field data to central data base or server an android app (e.g. DS file) can be used. Through the (DS file) app the PDA gets access to the server.

Once the filed crews have uploaded their field data, the data sets get checked either at the level of the BPKH office or the central office in MoEF (KLHK) or both for obvious errors or plausibility issues. For this purpose, each cluster will be checked and the data corrected (data cleansing) if necessary (figure 12).

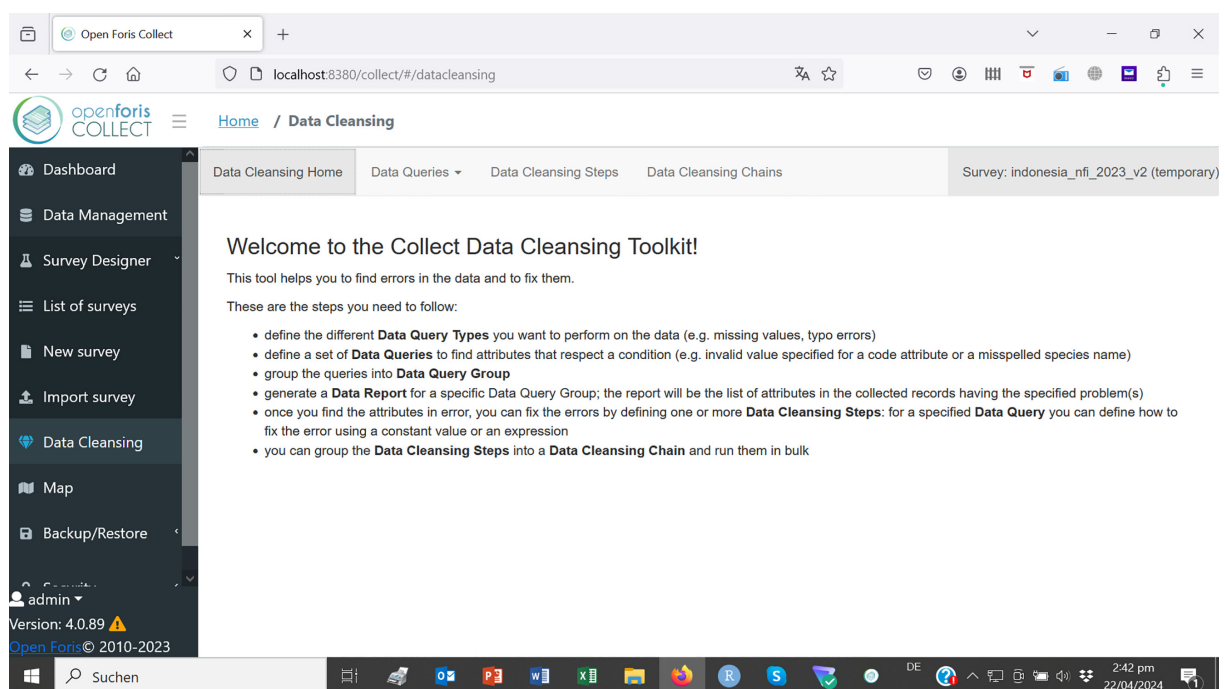


Figure 12 Data cleansing module for field data with Collect

After the quality control of the data sets, the responsible officer in either the respective BPKH office or at MoEF/KLHK level compiles all the records from the field work in a Collect file on the server for storage, further processing and analysis.

Specific queries and criteria for data cleansing for the NFI still need to be developed.

3.4.2 Data analysis

For data analysis the software systems to be used are not yet decided. One option is to use Open Foris Calc. OF Calc is a user interface which allows for developing tailored data analysis modules and aggregation of results for reporting in *Saiku*. The actual computational tasks are done within *R*. RStudio is used for programming and testing the calculation modules.

The modules are developed according to the data and reporting needs for the estimates of expected outputs as defined in the estimation design (chapter 2.4). The scripts for calculation are written in *R* and have to follow the indications for design parameters down to every single parameter of all the forest and land attributes included in NFI data collection as recorded through Collect and Collect mobile.

When new data are entered into the database, the results can be rerun in Calc without RStudio. Calc automatically aggregates the results for *Saiku*, a software tool to generate reports. From *Saiku* the result tables can be exported as Excel or CSV files for other applications for further developing tables and reports.

However, the data sets can also be exported from OF Calc in csv format, before entering the process chain in the Calc modules as raw data sets and processed and analyzed with other software systems including MS Excel. The latter is useful for smaller data sets and for testing the correctness of the OF Calc modules, R scripts and the process chains of the calculations.

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5 Annexes

5.1 Sample size calculation

Sample size for the new Indonesian NFI was calculated for each stratum and island groups based on the variability of stand attributes (i.e., above-ground biomass (AGB) or basal area) and expected precision (allowable sampling error) using the following Cochran (1977) formula:

$$n = \left(\frac{t_{\alpha/2, n-1} \cdot CV}{SE} \right)^2$$

where: n is sample size (number of cluster-plots), CV is variation coefficient (%) of a stand attribute (i.e., AGB or basal area), and SE is allowable sampling error (i.e., estimation precision). This formula was applied for each stratum as follows:

- For Stratum 1 (dry land, swamp, and plantation forests), the CV was calculated based on mean and standard deviation of AGB from old NFI data (in the period 2015–2022), which was ranging from 41.0% to 63.5%, depending on island group. The Stratum 1 used SE of 5–10% and a sample size increment of 10% to compensate for non-response.
- For Stratum 2 (trees outside forest, TOF), the CV was calculated based on mean and standard deviation of basal area data from a community forest inventory in Java, which was 62.1% and then applied to other islands due to unavailability of such data for the other island group. The TOF stratum uses SE of 15% by considering available NFI budget, and it uses a sample size increment of 7% to compensate for non-response. Tiryana (2023) further explains the calculation of sample size for TOF.
- For Stratum 3 (mangrove forest), the CV was calculated based on mean and standard deviation of AGB from old NFI data (in the period 2015–2022), which was ranging from 29.9% to 82.6%. The Stratum 3 uses SE of 10–15% and a sample size increment of 15% to compensate for non-response.

To systematically distribute the calculated sample sizes for each stratum and island group, the following formula was used to calculate distances among hexagon centroids:

$$k = \sqrt{\frac{A}{1.16n}}$$

where: k is hexagon spacing, A is stratum area (m^2), n is sample size, and 1.16 is an expansion factor for the hexagonal grids. The calculated spacings (k) was then adjusted to nearest 5 km (for Stratum 1 and 2) or 2.5 km (for Stratum 3) to facilitate further hexagonal grids division for sub-national forest inventories later.

The sample size and grid spacing calculations above resulted in a total sample size of 3632 cluster-plots, consisting of 2512 cluster-plots for the Stratum 1 (dry land, swamp, and plantation forests), 517 cluster-plots for the Stratum 2 (TOF), and 603 cluster-plots for the Stratum 3 (mangrove forest). Table A1, A2, and A3 provide detailed results of the sample size and hexagon spacing calculations for each stratum and island group.

Table A1. Sample size and hexagon spacing for Stratum 1 (dry land, swamp, and plantation forests)

No	Dryland, swamp, and plantation (Stratum 1)	Area (ha) ¹⁾	AGB (ton/ha)			Sample size calculation				Hexagon spacing (km)
			Mean	Stdev	CV (%)	SE (%)	n ²⁾	n*1.16	Distance (km)	
1	Bali-Nusa	2,654,039.3	270.19	159.63	59.1	10	148	171	12.5	10
2	Java	2,743,809.4	223.64	142.03	63.5	10	170	198	11.8	10
3	Kalimantan	27,150,376.6	273.32	131.53	48.1	5	391	454	24.5	20
4	Maluku	4,862,061.7	255.21	111.69	43.8	5	324	376	11.4	10
5	Papua	32,910,644.1	413.94	169.61	41.0	5	284	329	31.6	25
6	Sulawesi	9,074,388.2	228.97	109.35	47.8	5	386	431	14.5	15
7	Sumatra	13,351,574.0	310.19	164.80	53.1	5	477	553	15.5	15
Total		92,746,893.4								2512

1) Source: Land cover map 2022, which included both "Kawasan Hutan (Forest Area)" and "Areal Penggunaan Lain (APL, Other Use Areas)"; 2) Including 10% sample size increment

Table A2. Sample size and hexagon spacing calculations for Stratum 2 (trees outside forest, TOF)

No	TOF (Stratum 2)	Area (ha) ¹⁾	Basal area (m ² /ha)			Sample size calculation				Hexagon spacing (km)
			Mean	Stdev	CV (%)	SE (%)	n ²⁾	n*1.16 ³⁾	Distance (km)	
1	Bali-Nusa	2,452,812.4	8.55	5.31	62.1	15	70	71	18.6	15
2	Java	4,421,008.3	8.55	5.31	62.1	15	70	87	22.5	20
3	Kalimantan	14,758,864.4	8.55	5.31	62.1	15	70	86	41.4	40
4	Maluku	2,302,882.9	8.55	5.31	62.1	15	70	66	18.7	15
5	Papua	3,670,944.0	8.55	5.31	62.1	15	70	42	29.6	20
6	Sulawesi	6,036,443.9	8.55	5.31	62.1	15	70	71	29.2	25
7	Sumatra	16,139,886.5	8.55	5.31	62.1	15	70	94	41.4	40
Total		49,782,842.4								517

1) Source: Land cover map 2022, which included both "Kawasan Hutan (Forest Area)" and "Areal Penggunaan Lain (APL, Other Use Areas)"; 2) Including 7% sample size increment; 3) Including sample size adjustment after trying different hexagon spacing

Table A3. Sample size and hexagon spacing calculations for Stratum 3 (mangrove forest)

No	Mangrove (Stratum 3)	Area (ha) ¹⁾	AGB (ton/ha)			Sample size calculation				Hexagon spacing (km)
			Mean	Stdev	CV (%)	SE (%)	n ²⁾	n*1.16	Distance (km)	
1	Bali-Nusa	36,144.6	137.53	55.14	40.1	15	32	37	3.1	2.5
2	Java	44,922.3	70.94	40.56	57.2	15	64	74	2.5	2.5
3	Kalimantan	568,782.2	196.10	161.89	82.6	15	134	155	6.1	5.0
4	Maluku	273,489.1	231.45	69.17	29.9	10	39	46	7.7	7.5
5	Papua	1,542,803.2	223.14	70.34	31.5	10	44	51	17.4	15.0
6	Sulawesi	154,164.9	138.67	114.08	82.3	15	133	154	3.2	2.5
7	Sumatra	602,174.3	137.26	84.19	61.3	15	74	86	8.4	7.5
Total		3,222,480.5						603		

1) Source: Land cover map 2022, which included both "Kawasan Hutan (Forest Area)" and "Areal Penggunaan Lain (APL, Other Use Areas)"; 2) Including 15% sample size increment

5.2 Maps of NFI cluster distribution and panels

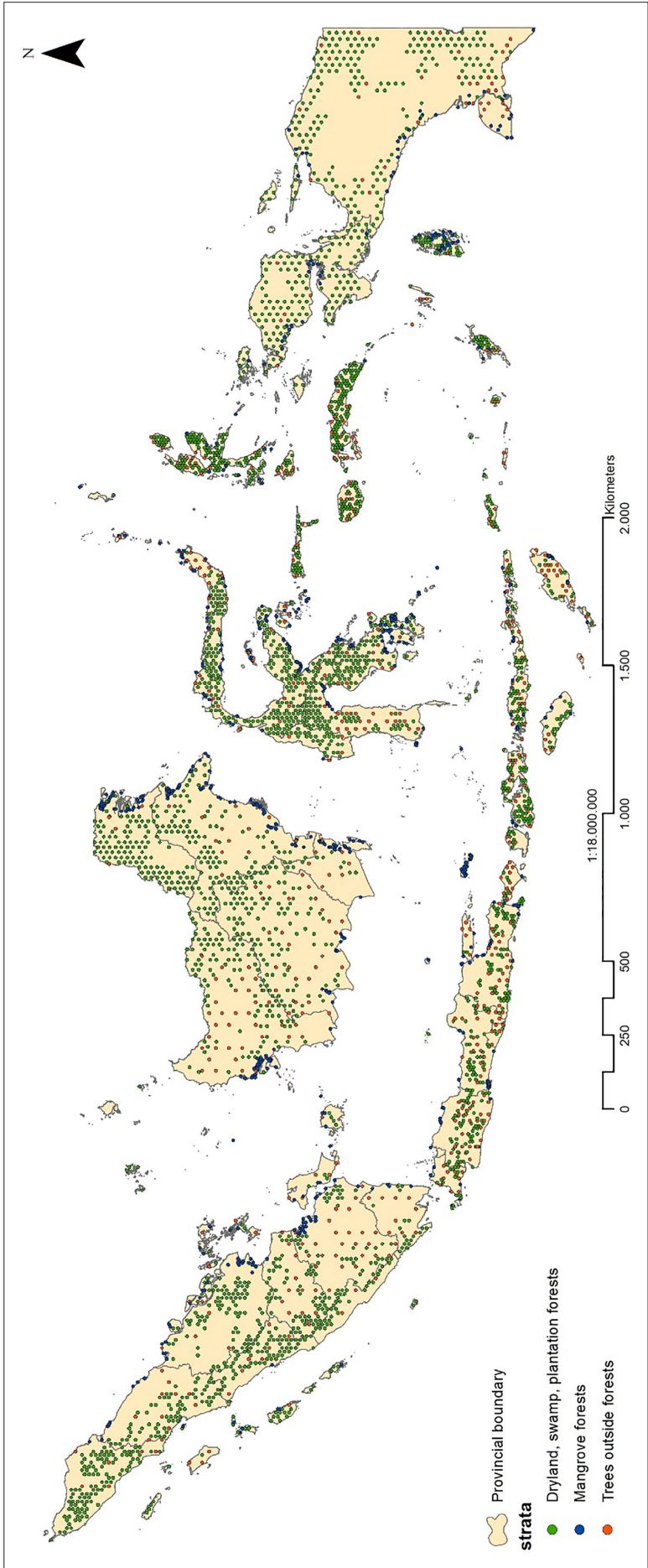


Figure A1 NFI cluster distribution all strata and all panels

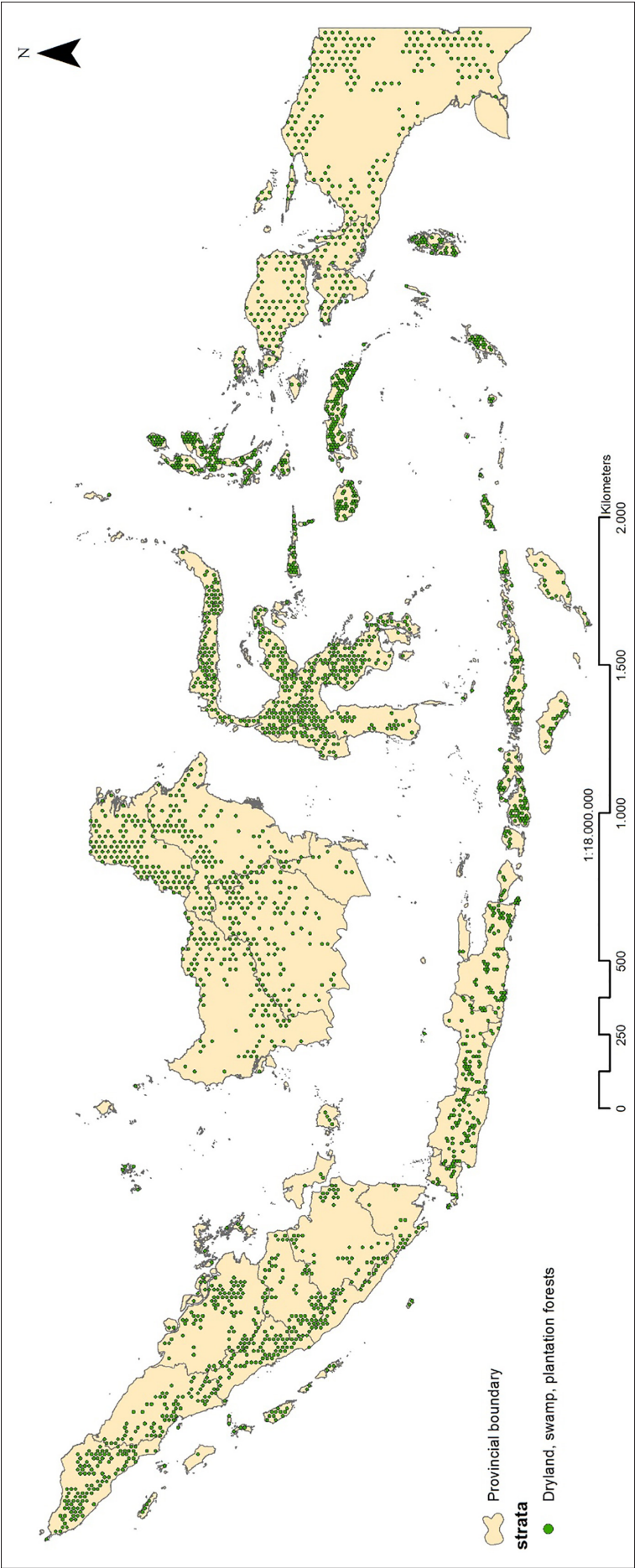


Figure A2 NFI cluster distribution stratum 1 (dryland, swamp and plantation forests) on all panels

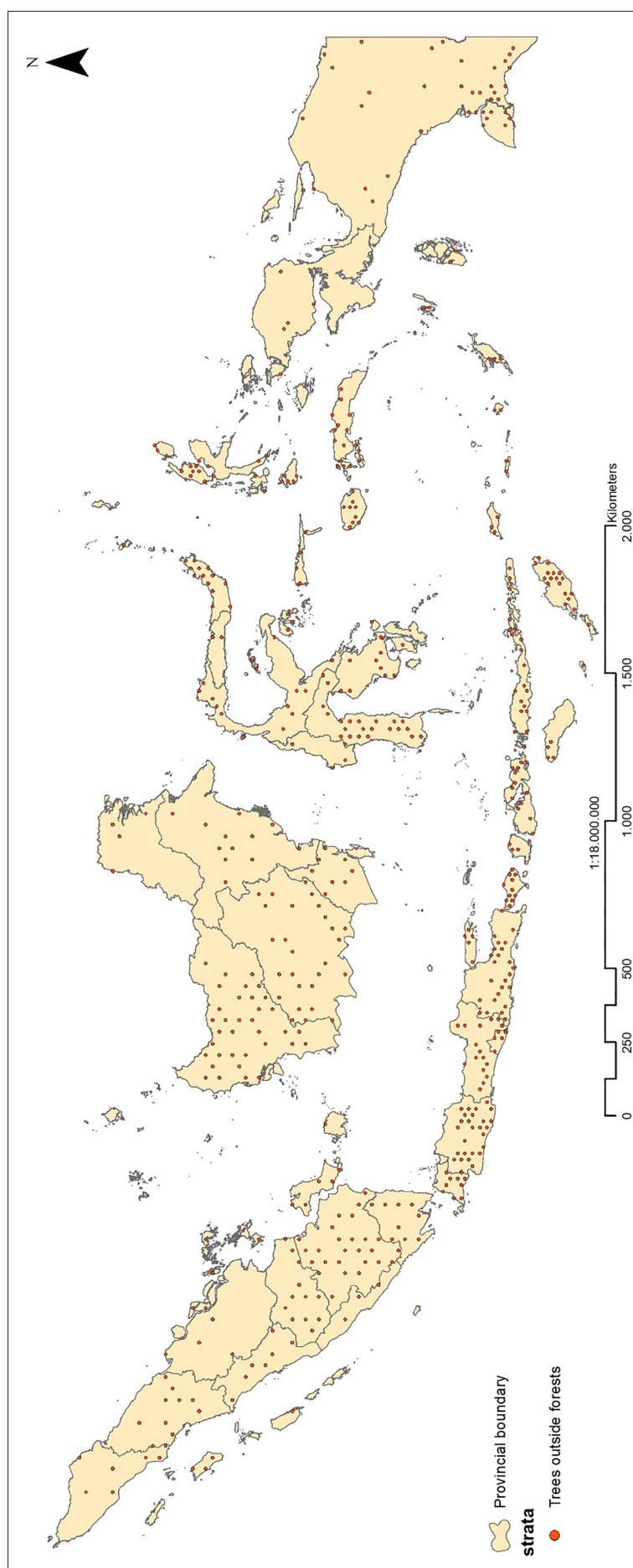


Figure A3 NFI cluster distribution stratum 2 (trees outside forests) on all panels

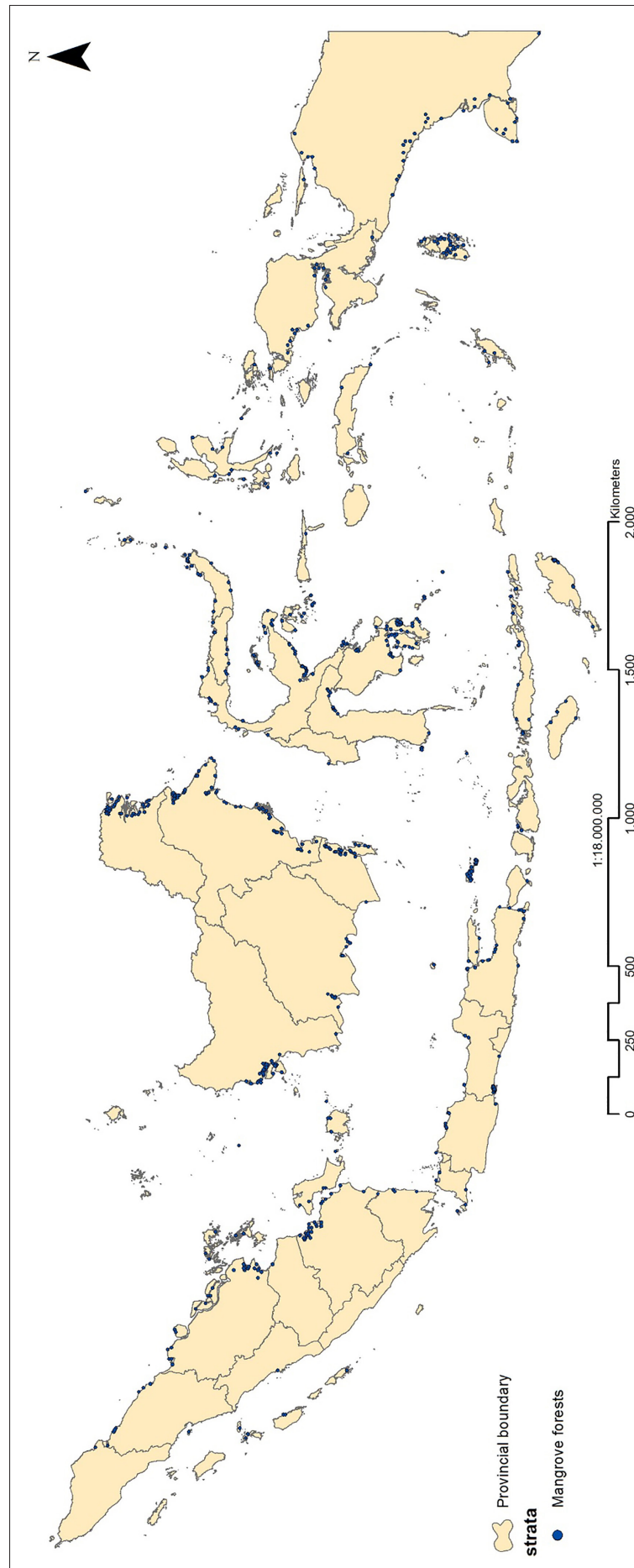


Figure A4 NFI cluster distribution stratum 3 (mangrove forests) on all panels

