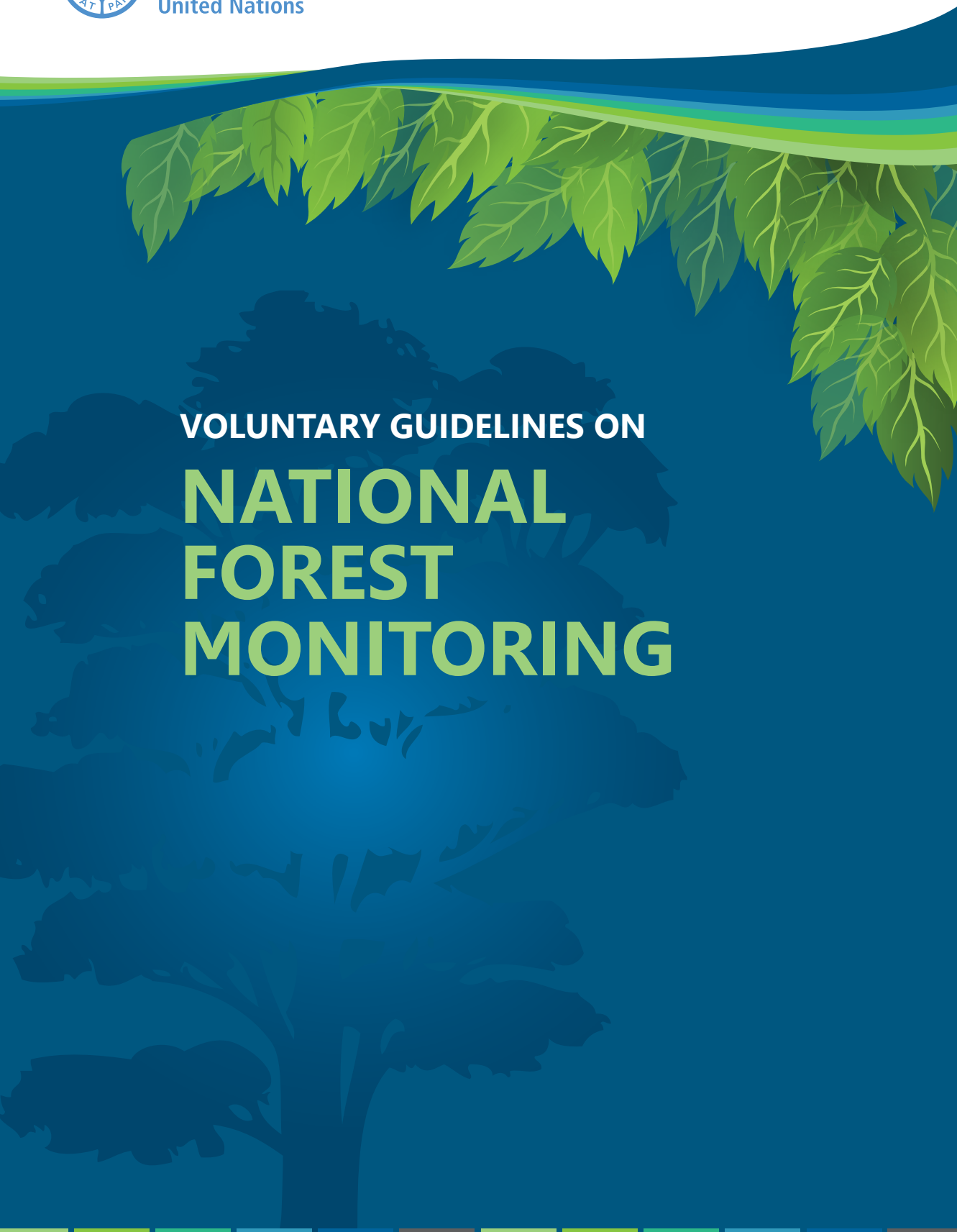
Food and Agriculture Organization of the United Nations



VOLUNTARY GUIDELINES ON NATIONAL FOREST MONITORING

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NATIONAL FOREST MONITORING

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

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Contents

Boxes

Foreword

Evidence-based policies and practices that support highly productive and sustainably managed agricultural sectors are key to achieving FAO's goals of eradicating hunger and eliminating poverty for the benefit of present and future generations. To achieve these goals, stronger national capacities to collect, compile and analyse data, and to generate and disseminate information tailored to specific audience needs are essential.

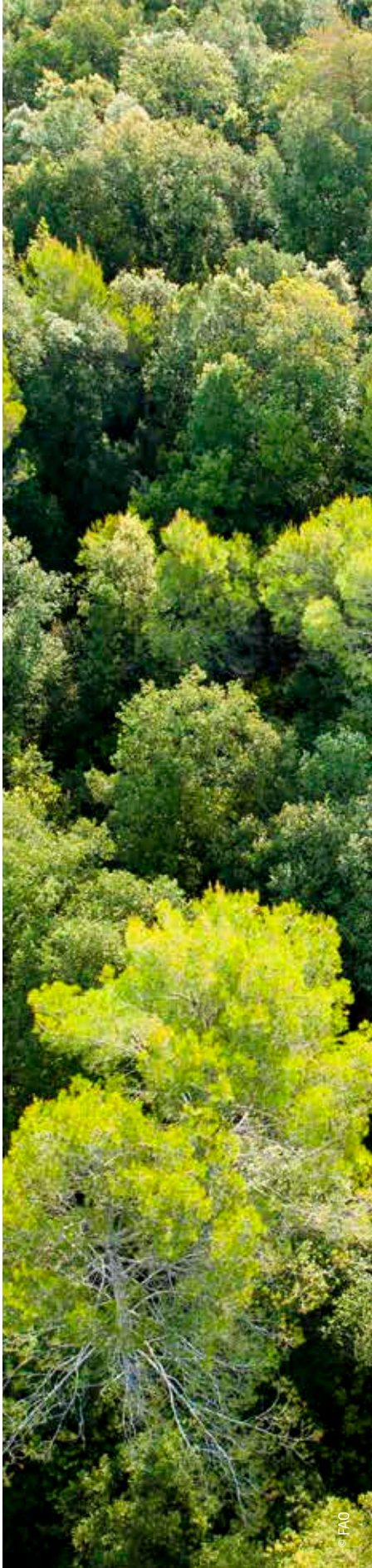
Understanding forest resources and their changes is key to national and international environmental and developmental policy processes and is required by many international agreements, including the United Nations Framework Convention on Climate Change (UNFCCC), the Convention on Biological Diversity (CBD), the United Nations Convention to Combat Desertification (UNCCD), the UN Forest Instrument and the Sustainable Developments Goals (SDGs).

Consequently, the demand for reliable and up-to-date national forestry data and stronger analytical capacities at a national level has grown considerably in recent years. In response, forums such as the 16th Conference of the Parties (COP16) have asked the UNFCCC to undertake activities to develop robust and transparent national forest monitoring systems for REDD+. Similarly, the 21st Session of the Committee on Forestry (COFO21) recommended further work with member countries to prepare voluntary guidelines on national forest monitoring.

The guidelines at hand draw on the rich experiences and lessons learned from FAO member countries and FAO national forest monitoring projects and initiatives, as well as key inputs provided at international workshops and technical meetings and by institutional partners and stakeholders. They are designed to support member countries' efforts to strengthen their national forest monitoring capacities, increasing their transparency and long-term reliability. They offer 'good practice' principles and a general framework, as well as tools for planning and implementing multi-purpose national forest monitoring grounded in nationally appropriate and scientifically sound practices that account for domestic information needs and international reporting requirements.

FAO is pleased to have coordinated the development of these voluntary guidelines and congratulates member countries, organizations, institutions, and authors that prepared and adopted this important tool to strengthen sustainable forest management at national and global levels.

Ms Eva Müller
Director, Forestry Policy and Resources Division (FOA)Forestry Department



Introduction

National information needs on forests have grown considerably in recent years, evolving from forest area and growing stock information to key aspects of sustainable forest management, such as the role of forests in the conservation of biodiversity and the provision of other ecosystem services. More recently, information on changes in carbon stocks, socio-economic aspects including the contribution to livelihoods and poverty reduction, governance and broader land use issues has become critical for national planning.

The forest sector faces increasingly diverse information needs regarding land use and forest resources. This information is also necessary for policy-makers and other stakeholders to effectively enhance the role of forests in reducing the impact of climate change and providing other key ecosystem services. To help realize the contribution of forests to sustainable energy and food security, policy-makers require more and better data, including information on trends and outlooks and the broader context, such as demand for food, energy and wood fibre and employment and rural development issues. They must also meet the growing demand for evidence of forest management outcomes.

Stronger national capacities are essential to collect, compile and analyse data and to generate and disseminate information tailored to audience needs. In 2010, however, only 45 countries worldwide were able to assess changes in forest area and characteristics through consecutive systematic national forest inventories. [1] Moreover, it is likely that these do not fully reflect the additional national information needs outlined above.

Comparability and consistency are key elements to providing timely and reliable forest information at different scales. In this context, countries need to establish and consolidate national forest monitoring systems. Guidance on how to collect, compile and analyse forest information is fundamental to this endeavour.

Establishing and running a National Forest Monitoring System (NFMS) constitutes a complex scientific-technical exercise and an organizational and institutional challenge. The process has a direct link to policy as it informs management and decision-makers about the sustainable use of forest resources and the efficient protection and conservation of forest ecosystems. Accordingly, an NFMS supports governments in fulfilling their obligations to continually develop, monitor and report on "forest resources", which may include trees outside forests as well as other land cover classes.

The aim of these Voluntary Guidelines is to assist with the creation and operation of NFMSs. The guidelines include good practice principles, guidelines and a general framework. It also incorporates a set of decision-support tools for planning and implementing a multi-purpose NFMS grounded in nationally appropriate and scientifically sound practice, taking into consideration domestic information needs and reporting requirements.

This document is intended as a technical reference for governmental bodies in charge of forest monitoring, educational and research institutions, the public and private sectors, and members of civil society concerned with national forest monitoring (NFM). It is important to bear in mind that national circumstances vary in terms of biophysical conditions (e.g. forest types and forest utilization practices, road infrastructure), institutional frameworks, economic challenges and possibilities, management and use (the historical development of forest management and forest services, forest research and education, traditions in forest monitoring), among others. Accordingly, there is no "one-size-fits-all" approach for NFM. Instead, various suitable and good technical and organizational options must be combined to achieve efficient implementation. The NFM approach must be target-driven, oriented towards specified objectives and realistically feasible within the available time, budget and human resources.

It is expected that these Voluntary Guidelines will enable member countries to set up and strengthen NFMSs, by addressing principles and key guidance elements required for a transparent, reliable and long-term process. The guidelines take into consideration existing guideline initiatives such as the IPCC's Good Practice Guidance for Land Use, Land-Use Change and Forestry, which will in turn benefit from implementation of these Voluntary Guidelines on National Forest Monitoring as member countries consolidate their NFMS.

1 FAO. 2010. Global forest resources assessment 2010: Main report. FAO Forestry Paper No. 163. Rome.

Acknowledgements

The Voluntary Guidelines were made possible thanks to the contributions of many dedicated people and institutions that willingly provided time and specialist expertise during the formulation and review process.

The first part of the document (sections 1 and 2) was validated during six Regional Forestry Commissions (2013-2014), FRA regional meetings and different technical meetings held during 2013 and 2014, and was endorsed by COFO in 2014. The technical validation of the second part of the document was finalized via an online consultation, which allowed experts from around the world to share their opinions and contributions. As a final step, an expert and user workshop was held in Rome (November 2015) to gather further feedback from international experts and potential users of the guidelines.

The preparation of the guidelines was coordinated by David Morales-Hidalgo. Leads authors were, Christoph Kleinn (Georg August Universität Göttingen, Germany), David Morales-Hidalgo (FAO) and Charles T. Scott (USFS, United States), and substantial inputs were provided by Dan Altrell (FAO), Thomas J. Brandeis (USFS, United States), Anne Branthomme (FAO), Luca Birigazzi (FAO), Marco Boscolo (FAO), Soma Chakrabarti (FAO), Kevin Cueva (FAO), Joberto Freitas (BFS, Brazil), Javier García (FAO), Matieu Henry (FAO), Selmi Khemaies (FAO), Kari Korhonen (LUKE, Finland), Andrew J. Lister (USFS, United States), Anssi Pekkarinen (FAO), Marco Piazza (FAO), Carla Ramirez (FAO), Quentin Renard (FAO), K.D. Sing (India), Gael Sola (FAO), Rebecca Tavani (FAO), Zoltán Somogyi (Hungarian Forest Research Institute, Hungary), Lauri Vesa (LUKE, Finland) and James A. Westfall (USFS, United States).

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Acronyms

C&I	Criteria and indicators (for sustainable forest management)
CBD	United Nations Convention on Biological Diversity
CIRAD	French Agricultural Research Centre for International Development
DBH	Diameter at breast height
ECOSOC	United Nations Economic and Social Council
FAO	Food and Agriculture Organization of the United Nations
FRA	FAO's Global Forest Resource Assessment
GPS	Global positioning system
IPCC	Intergovernmental Panel on Climate Change
MQO	Measurement tolerances and measurement quality objectives
NDVI	Normalized Difference Vegetation Index
NFI	National forest inventory
NFM	National forest monitoring
NFMA	National forest monitoring and assessment (FAO)
NFMS	National forest monitoring system
NGO	Non-governmental organization
QA/QC	Quality assurance/quality control
REDD+	Reducing Emissions from Deforestation and Forest Degradation (UNFCCC)
SDG	Sustainable Development Goals
TOF	Trees outside forests
UN	United Nations
UNCCD	United Nations Conventions to Combat Desertification
UNFCCC	United Nations Framework Convention on Climate Change
UNFF	United Nations Forum on Forests
UN-REDD	United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries

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Part A

Background and principles

Section I
Background

Section 2
Principles of national forest monitoring

SECTION 1

Background

1.1 General role of national forest monitoring

For the purpose of this document, *national forest monitoring* is viewed as a comprehensive process that includes the systematic collection, analysis and dissemination of forest-related data, and the derivation of information and knowledge at regular intervals to allow the monitoring of changes over time. It focuses on national level data and information on forests and trees outside forests, their condition, values and uses. The information obtained supports forest-related decision-making at international, national and sub-national levels by providing timely, relevant and reliable information.

The term *national forest inventory* (NFI) is commonly used to describe the technical process of data compilation and analysis of forest resources from a multitude of data sources, including field inventories and remote sensing, to estimate relevant forest characteristics at particular points in time. *National forest monitoring* (NFM) is a much more comprehensive process that includes the assessment, evaluation, interpretation and reporting of data and the derivation of information, usually from repeated inventories, that allows for the monitoring of change and trends over time (Figure 1). In many countries, however, especially where inventories are repeated over time, the term NFI is traditionally used also to describe the whole process of national forest monitoring.

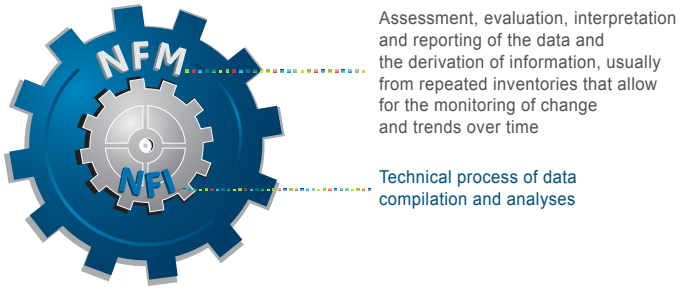

Figure 1: Relationship between national forest monitoring and the national forest inventory

Other additional related terms include *national forest assessment*, defined here as the systematic process of gathering, collecting, analysing and using information from diverse sources to assess the value, quality or importance of forests at national level, taking into account all their functions; and *national forest monitoring system* (NFMS), which comprises the people, institutions and resources that implement national forest monitoring at the country level in collaboration with other stakeholders. Generally, a NFMS is led by a governing body responsible for its conceptualization, planning and execution within a clear and well-defined mandate, based on the principles and elements introduced in this document.

The monitoring of forest resources is by no means new, and the box below presents a 'brief history'.

Box 1: A brief history of national forest monitoring

The monitoring of forest resources has a long history. For centuries, forest managers regularly have carried out standard data collection in forests on a regular basis to provide a basis for proper mid-term planning and to optimize forest management. Increasingly, conservation groups and other stakeholders are requesting data on forest ecosystems and forested landscapes (e.g. in relation to defining bio-corridors or establish protected areas).

National forest monitoring informs forest-related decision-making at the national level.

Historically, national interest in forests was linked to wood production and the use of forest land to meet future demand for conversion to other land uses. From the 1960s to the 1980s, national-level forest inventory projects were installed in developing countries and funded by international organizations and bilateral programmes for technical cooperation. Many were implemented through FAO. These projects usually produced valuable information linked to a single point in time, but were unsustainable over the long term: data frequently became inaccessible, capacity was not maintained or developed further, and there was a lack of permanent institutions to manage data sets and establish a permanent national level forest monitoring programme.

FAO produced several major publications on planning and implementing forest inventories at this time*, and attempts were made to develop forest inventory data processing systems that would enable basic standardized analyses.

* Husch, B. 1971. *Planning a forest inventory*. FAO Forestry and Forest Products Studies No. 17. Rome.
FAO. 1981. *Manual of forest inventory*. FAO Forestry Paper No. 27. Rome.

1.2 Goals and scope of national forest monitoring

The goal of national forest monitoring is to generate a reliable data and information base:

- To support the formulation, monitoring and adjustment of national and sub-national level policies related to forests and forested landscapes including, increasingly, development and on socio-economic policies;
- To inform interested citizens and stakeholders (including forest owners and dwellers, environmental NGOs, forest-based industries, research organizations, academia, citizens, etc.) about the status characteristics, services and development of national forest;
- To facilitate discussions and the development of agreements at the international level and to submit regular reports in accordance with international conventions and processes, as required for signatory nations, using pre-defined questionnaires;
- To provide baseline data to enable the measurement of progress towards sustainable forest management.

As such, national level forest monitoring pursues the same goals as many other data-gathering activities implemented by national governments, either permanently or on a regular basis. Most nations undertake a population census at fixed intervals to inform the government about the socio-economic characteristics of the population. Other examples of national data gathering include the collection of economic data to adjust fiscal, monetary and economic policies; and the gathering of agricultural data to monitor government subsidies.

Forest monitoring may be viewed as a part of data requirements for good "environmental governance". The presence of a comprehensive, reliable and transparent database is essential for informed decision-making, and to communicate and defend policy on scientific grounds.

1.3 Increasing information needs at the national level

For decades, governments in developing countries have considered long-term information on forest resources and the forest ecosystem to be of lesser importance compared to other national information. However, views on the relevance of up-to-date forest information have altered significantly in recent years. By highlighting the vital role that forests play in biodiversity, climate change, combating desertification, securing livelihoods and promoting efforts to increase food security, the United Nations has assigned a much higher priority to forests, their conservation and sustainable management, and supports Member States in their efforts to protect and sustainable develop their forests.

The sustainability of forest management and forest policies is at the core of national forest planning, and national forest monitoring should provide the scientific information base to support implementation and monitoring of national forest programmes and forest development plans. The criteria for sustainable forest management, therefore, define the framework for national forest monitoring, while the indicators for sustainable forest management define the core set of attributes to be surveyed, assessed and monitored in national forest monitoring (see section 1.5).

National forest monitoring systems (NFMS) are expected to form part of international mechanisms (including REDD+) that provide payment for environmental services. Under these mechanisms, developing countries will receive financial compensation for the successful implementation of sustainable pro-forest policies. In many programmes, the corresponding payments will be strictly performance-based and released only when credible evidence exists that the agreed and announced goals have been achieved. This evidence is largely generated by forest-monitoring efforts (Box 2).

However, governments in many developing countries have not invested in permanent national forest monitoring, which has resulted in a considerable capacity gap. To cope with increasing information needs and growing demand for expertise in national forest monitoring, comprehensive efforts need to be undertaken to build or strengthen national capacity. This requires the establishment of an institutional setting for forest monitoring and related activities.

Box 2: Forest-related information is increasingly valued

For a long time, national-level forest inventory and monitoring was viewed exclusively as a forestry issue and received little attention from other sectors and governments. In developing countries, governments provided only minimal efforts or investments, and national forest inventory and monitoring was implemented mostly through technical cooperation projects via international or bilateral cooperation. This took the form of projects rather than programmes, which were limited in time and scope and not institutionalized within national systems.

This situation has changed considerably. Many countries now recognize forests as national as well as global assets, about which they need up-to-date data and information in order to monitor status and changes over time, as a basis for informed decision-making on a wide range of issues.

National forest monitoring may be considered a standard survey activity similar to other information-gathering activities undertaken by governments to remain informed (e.g. population census, community and economic surveys).

1.4 Key issues and key questions for national forest monitoring

National forest monitoring in these Voluntary Guidelines is based on the premise that forests are a single land-use system embedded within other land-use systems, which are in turn integrated within landscapes, and that the forestry sector is closely interlinked and interacts with other sectors.

Based on this understanding of national forest monitoring, the first key issue is the requirement to meet multiple information needs. National forest monitoring produces information that improves understanding of the roles of trees and forests in terms of the relationships and interactions between different land uses. It aims to inform decision processes towards more sustainable management of these landscapes, in order to maintain and enhance their environmental and socio-economic service functions, both to support sustainable development and to contribute to the well-being of people and societies. National forest monitoring, therefore, needs to take into account not only biophysical dimensions, but also economic and social dimensions. For example, national forest monitoring systems are of interest to various domains including all those at a national level related to land use (e.g. forestry, agriculture, biodiversity conservation, urban development, wood industry, community development, etc.).

The second key issue relates to the increasingly diversified uses of forests: national forest monitoring should not focus exclusively on lands defined as forests, but include all other lands that have trees – a resource usually referred to as "trees outside forests". It should not only monitor biophysical stocks, but also the use of forests and trees. This implies a need both for measurements of biophysical variables and information (e.g. through interviews) from forest owners and those who use the forest or who benefit from forests. Such information will help countries to understand the current uses and expectations of forest users, and gain relevant insights about the effectiveness of forest-related policies and potential trends.

The third key issue is that data generated from monitoring also informs research. Data from national forest monitoring efforts are increasingly used in research projects and as crucial inputs for discussions within the UNFCCC, particularly in the context of large area mapping and estimation of carbon stocks and biodiversity indicators.

National circumstances vary with respect to land uses and forest types, the socio-economic and environmental role of forests, the capacities of national institutions, and the importance accorded to national forest monitoring on the political agenda. The expectations of information users also vary. However, a number of key technical questions commonly drive national forest monitoring (Box 3). Ideally, these questions are determined and collated by a comprehensive formal information needs assessment, a process that should be closely coordinated by experts in forest monitoring with as many forest information users as possible.

Box 3: Key questions in national forest monitoring

- Where are forests located and what is the extent and composition (area by forest type and ownership, growing stock, biomass, carbon, diversity, site fertility, etc.)?
- What is the status of the forest in terms of quality and vitality? Are there any threats?
- How are forests and tree resources being used? How much is being utilized (e.g. timber harvest)? Is it sustainable?
- Who is benefiting from/depending on forests? And how?
- What changes and trends in the development of different forest characteristics and functions are occurring?
- Can indicators or drivers of these changes be identified?
- What are the relationships between different variables?
- How accurate and precise are the estimates?

Various data sources are employed in national forest monitoring, the most important being: (i) sample-based field observations; (ii) remote sensing; (iii) national statistics, if available, on land use and harvests; (iv) allometric models and (v) information from previous monitoring studies.

National forest monitoring employs the most efficient blend of data sources to adjust to specific goals. For example, when the production of maps and spatially explicit analysis is a key output, there needs to be a strong remote-sensing component. If estimating the statistical precision of core attributes is a major focus, a sufficiently large sample size of field observations is crucial, as are appropriate allometric models.

There is no "one-size-fits-all" approach for national forest monitoring. Instead, NFM is a persistently demanding process of balancing different and possibly competing technical and policy priorities. As such, there are likely to be trade-offs, as is the case in any negotiated national process.

The design of national forest monitoring systems involves a number of technical questions. This, at times, leads to perceptions that monitoring is a purely technical exercise. Box 4 shows that this is not the case and suggests that there are two major dimensions: the technical and scientific dimension of producing relevant and credible data, and the policy dimension which involves communicating the implications of these data effectively to different target audiences (Box 5). National forest monitoring must never be exclusively technology driven or considered solely as a technical task; it is never an end in itself, but rather serves a specific function within complex information and decision processes.

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Box 4: Two dimensions of national forest monitoring

National forest monitoring has two major dimensions: (i) the technical and scientific dimension of producing relevant, high-quality and credible data, and (ii) the policy dimension.

When designing and implementing a national forest monitoring system, both dimensions must be kept in equal focus. Technology-driven approaches to comprehensive data collection should be avoided, unless their effectiveness can be proven.

Planners of national forest monitoring systems must understand the policy processes that they support, and must be able during the planning phase to translate the information requirements of these processes into attributes that can be measured or observed in forest inventory systems.

Likewise, during the analysis and reporting phase they should be able to communicate the implications through key messages that are relevant and meaningful for those who drive related policy processes.

Box 5: Good decisions require good information

This and other general statements are frequently used as a rationale for data collection projects. Such "linear" assumptions are also employed when establishing national forest monitoring systems. Similar statements are used in scientific research when working to improve field data collection and remote-sensing techniques.

However, it should be noted that little available scientific research or evidence regarding national forest monitoring establishes a clear relationship between information quality and decision quality; and political sciences stress that policy processes do not usually follow simple linear and rational lines alone.

Although it is scientifically relatively straightforward to quantify data quality from statistically based estimations, it is much more difficult to evaluate "information quality" and eventually to communicate policy implications of this data for "quality decisions".

Nevertheless, reliable scientific information from national forest monitoring, if appropriately communicated to policy-makers, constitutes a powerful tool and evidence base for stakeholders, including the public.

1.5 Indicators of sustainable forest management as core attributes to be assessed in national forest monitoring

Sustainable forest management is the ultimate goal of national forest programmes and policies. This requires criteria and indicators that define the core attributes of national forest monitoring and assessment:

Criteria and indicators are tools used to define, assess and monitor periodic progress towards sustainable forest management in a given country or in a specified forest area, over a period of time. Indicators are parameters which can be measured and correspond to a particular criterion. They measure and help monitor the status and changes of forests in quantitative, qualitative and descriptive terms that reflect forest values as seen by those who defined each criterion.[2]

Sustainable forest management consists of the following seven thematic elements, which are acknowledged by the UN Forum on Forests and used as a reporting framework for FAO's Global Forest Resource Assessment (FRA) Programme:[3]

a. Extent of forest resources[4]
b. Forest biological diversity
c. Forest health and vitality
d. Productive functions of forest resources
e. Protective functions of forest resources
f. Socio-economic functions of forests
g. Legal, policy and institutional framework.

National forest monitoring involves recording data, producing information and reporting predominantly on elements 1-6, focusing on status and trends.

The UN Forestry Instrument makes explicit reference to these seven thematic elements when recommending countries to develop monitoring programmes and design research programmes.[5] Forest monitoring accompanies these processes by providing information for their design and monitoring.

2 See www.fao.org/forestry/sfm/85101/en/

3 See www.fao.org/forestry/sfm/24447/en/

4 Here, the term "forest resources" also includes "trees outside forests" (TOF).

5 For example, see: UNFF/ECOSOC. 2007. *Official Records, 2007, Supplement No. 22 (E/2007/42 E/CN.18/2007/8): "V. National policies and measures" paragraph (r) and (w); and "VI. International cooperation and means of implementation" paragraph (o).* New York, United Nations Forum on Forests Report of the seventh session/United Nations Economic and Social Council.

1.6 Forest monitoring as a complex undertaking

Forests are complex systems and their monitoring requires approaches and techniques that reflect this. National forest monitoring is driven by the interests of many stakeholders. It involves numerous actors and draws upon a variety of data and information sources, including remote sensing, field observations, existing maps, reports and other documents, and expert information. Data on many and diverse forest and landscape attributes are recorded, stored and processed, to serve as indicators for the production of required policy-relevant information.

The major scientific disciplines involved in the technical side of forest monitoring are forest mensuration, statistical sampling, statistical modelling, botany, remote sensing and information systems. Experts in all these fields are scarce if not largely absent in most developing countries. This is partly because large-area forest inventory and forest monitoring is rarely covered by academic curricula. Forest inventory courses usually focus exclusively on forest management inventories because these are needed in many countries to establish forest management plans, which in turn are a prerequisite for obtaining wood-harvesting permits.

1.7 Purpose of these Voluntary Guidelines

It is generally accepted that credible national forest monitoring needs to be based on sound scientific data so as to reduce disputes. Building capacity for this is vital at the national level in order to properly plan and implement such systems. These Guidelines therefore aim to respond to this capacity gap at the national level. They are intended as a technical reference for governmental bodies responsible for forest monitoring, educational and research institutions, the public and private sectors, and civil society.

While there is no such thing as a "best forest-monitoring practice", there are a number of widely accepted principles and basic elements for effective national forest monitoring system design. What appears to be missing within the available literature is a compilation of guiding principles for national-level forest monitoring, based on science and implementation experience, which also takes into account the wider context of adjusting monitoring methodologies to national circumstances. The Guidelines aim to fill this gap.

Since 2000, FAO has provided intensive support to countries through its National Forest Monitoring and Assessment (NFMA) Programme, and has developed an approach that can be adjusted to national circumstances and adopted in developing countries in need of assistance. This approach recognizes that national level forest monitoring systems need to be designed to reflect national circumstances and priorities (e.g. biophysical conditions, infrastructure, objectives, human and financial resources, policy priorities, etc.). It poses institutional as well as scientific challenges, with both policy and communications implications. These Guidelines build on the experiences and lessons learned by FAO member countries, and by past and current FAO projects and initiatives, including the Global Forest Resources Assessment Programme, the National Forest Monitoring and Assessment Programme, and the UN-REDD Programme.

The Guidelines are not intended as an inflexible set of instructions, but rather present trends and key issues to consider in the light of increasingly complex and negotiated national and global information needs with regard to forests. They present good practice principles, lessons learned, and selected methodologies and tools, within a general framework. This set of decision-support tools is designed to help plan and implement a multi-purpose national forest monitoring system grounded in nationally appropriate and scientifically sound practice.

1.8 Scope and goals of the Guidelines

The Guidelines cover both technical and scientific approaches to optimizing inventory, statistical modelling and estimation, and remote sensing, and also include guidance on strategic planning and communication and dissemination of results.

To summarize, the Guidelines offer a blend of scientific bases and implementation experiences that comprise a hands-on reference for those responsible for designing a national forest monitoring system. Scientific-technical details are not covered in detail, but are instead briefly addressed with signposts to the relevant scientific literature.

The Guidelines also contribute to developing basic standards (or elements of standards) that facilitate comparison in space and time. This includes standardization of terminology in order to avoid confusion in the wider forest-monitoring context, as terms may be used or understood in different ways in different contexts. This is not a question of which terminology is "right or wrong" or "correct or incorrect", but rather a matter of whether terms are clearly or not clearly defined (Box 6).

Box 6: Terminology is key in all surveys

Without clearly defined terms and methods, the results of an inventory cannot be unequivocally understood or interpreted, and cannot be properly communicated.

Section 2

Principles of national forest monitoring

As shown in the previous section, national forest monitoring:

- is never an end in itself, but instead informs decision-making processes;
- is used as an evidence base by a wide variety of actors;
- needs to meet an increasing variety of needs;
- needs to provide both scientific and socio-economic information;
- is highly context specific;
- is usually one component in broader decision-making processes.

While no overarching principles have been explicitly compiled before, various principles are present in different contexts. These include the "Forest Instrument" (the Non-Legally Binding Instrument for All Types of Forests), the "IPCC Guidelines for National Greenhouse Gas Inventory" and various UNFCCC Conference of Parties (COP) decisions[6] related to REDD+. These sources, as well as research and development in national forest monitoring to date, inform the principles presented below.

National forest monitoring systems encompass a variety of themes, which can be addressed by different groups of principles:

Governance principles
Refer to institutional settings and governance

Scope principles
Refer to the identification of information needs

Design principles
Refer to data collection and analyses (including sample-based field inventories and remote sensing analyses

Data principles
Refer to information generation, reporting and dissemination and in particular to data availability

Overall principles
Suggest general guidelines

Table 1: Principles of the Voluntary Guidelines on National Forest Monitoring

Governance principles	Principle 1: Country ownership and responsibility
	Principle 2: Legal and policy basis
	Principle 3: Landscape view
	Principle 4: Institutionalization of NFM
	Principle 5: Research infrastructure and capacity building
Scope principles	Principle 6: Participatory discussion process
	Principle 7: Satisfaction of national information needs
Design principles	Principle 8: Integration of and consistency with existing information sources
	Principle 9: Flexible approach
	Principle 10: Multi-purpose approach
	Principle 11: Feasibility including cost-efficiency
Data principles	Principle 12: A well-defined data and information-sharing policy
Overall principles	Principle 13: Credibility through transparency and quality
	Principle 14: Collaboration at the international level

6 See http://newsroom.unfccc.int

2.1 Governance principles

Principle 1: Country ownership and responsibility
Implementing a national forest monitoring system and generating a reliable database on forests and their uses is primarily a domestic issue. Knowledge generated by a national forest monitoring system informs national governments and provides inputs to facilitate informed decision-making. It also informs society and non-governmental organizations (NGOs), ensuring that speculation in policy discussions about the status of forests and related trends can be replaced by scientific evidence.

As such, national forest monitoring should be considered a standard data collection activity of governments to support informed decision-making and informed discourse.

National forest monitoring must, therefore, be based on country ownership. This is key for sustainability and to pave the way for a more comprehensive usage of the information generated. National ownership by government and other stakeholders should therefore be envisaged as part of the project from the outset (see Box 7).

Some of the principles discussed later (e.g. Principle 2: Legal and policy basis, Principle 4: Institutionalization of NFM, and Principle 5: Research infrastructure and capacity building) derive directly from Principle 1: Country ownership and responsibility.

Box 7: Need for national ownership

Lack of consideration and pro-active fostering of country ownership from the project outset was one of the major failures of early national forest inventory and national forest monitoring efforts, carried out by many donor and international agencies in the 1960-80s. Many of these inventories were implemented as projects with a defined lifespan, defined resources and without a clear follow-up vision.

Lack of country ownership likely resulted from a lack of awareness among national governments, unwilling or unable to invest in the project, and from a lack of attention to this important component on the part of donors.

In retrospect, with the exception of a few examples, these inventories produced relevant findings for specific points in time, but were not developed into long-term monitoring programmes has and did not result in sustainable capacity building at the country level.

In some cases, it remains clear whether the data are still available or accessible.

Principle 2: Legal and policy basis
In some contexts it may be helpful to establish a legal basis for national forest monitoring, for example, by adding a corresponding paragraph to a national forest law, as well as related policy. Defining a legal and policy may help to establish a formal link between the national forest monitoring system and a national forest programme, if such exists. This approach also supports country ownership (*Principle 1*) and may promote institutionalization (*Principle 4*), as well as stimulate full implementation of national forest monitoring (e.g. permitting measurement in private forests).

Principle 3: Landscape view
Forests form part of landscapes and as such are interwoven into a network of environmental functions and socio-economic interests, both local and at larger scales. Forest development is driven largely by forces outside the forestry sector. It is, therefore, essential to look at forests as one component within a forested landscape. Ideally, forest monitoring will be a component of landscape monitoring, which focuses on tree resources at landscape level rather than on forest resources alone. A variety of integrated land-use assessments have already provided successful experiences.

Adopting a landscape approach when developing a national forest monitoring system requires technical adjustments to the monitoring design. It will necessitate multi-sectoral coordination, as the mandate for national forest monitoring usually ends at the forest boundary.

Principle 4: Institutionalization of NFM
One of the distinct features of forestry is its long-term character, which consequently requires a long-term structure implemented through a permanent institution. A properly equipped national level institute – wherever it is located within the national administration – can promote:

- Long-term availability of data including adequate data management. This is an indispensable prerequisite for trend analysis from repeated observations, and for the framework of a defined data and information-sharing policy *(Principle 12)*.
- Long-term availability of expertise, in terms of monitoring techniques, data management

and analysis, and mainstreaming monitoring information into national and international policy processes.
- Long-term vision and adequate further development of approaches, enabling adjustments in scope and objectives, as well as continuity of related research. This supports flexible approaches (*Principle 9*).

The selection or development of an appropriate institution for a national forest monitoring depends on national circumstances and available capacity. This is a challenging task because national forest monitoring efforts, when for example implemented every five or ten years, typically exhibit a cyclic workload, which may cause difficulties for any permanent institution. One solution to this problem may be the implementation of data collection on a rolling basis, as is the case in Sweden and the United States of America.

Efforts should be made to build on existing national institutions and existing national capacities, while keeping in mind that long-term and secured adequate funding is required.

Principle 5: Research infrastructure and capacity building

Any national survey requires appropriate national capacities and a research infrastructure in order to be successfully implemented under country ownership. Both research infrastructure and capacities need to be strengthened in line with national circumstances, and both are long-term endeavours.

Capacity building includes both short-term training and long-term academic and technical education. It can be achieved either with national expertise or through international cooperation. FAO, for example, has long experience in designing and implementing training in forest monitoring in different country contexts. It makes sense, wherever possible, to combine training and education activities with design and implementation of the monitoring system and to offer interested staff the possibility of gaining hands-on experience.

Research plays an important role in national forest monitoring. During the planning phase, adjustments and optimization of the design are necessary to match the particular country circumstances. This task usually requires methodological expertise to develop an appropriate, nationally relevant design. The same is true for the estimation process, which needs to be designed in accordance with the sampling process. Many research questions arise during the planning phase for the monitoring design, especially concerning: the optimal integration of remote sensing; optimal field plot location, type, size and number; biomass and/or other allometric functions for species or species groups; analysis of different error sources, and so on. The design and implementation of a well thought out and scientifically planned pilot inventory should help to define an optimal design.

Research may play another important role once the data are present. In addition to standard analyses demanded by decision-makers, data sets from national forest monitoring usually offer plenty of opportunities for high-level research – an opportunity that is not fully exploited everywhere by research groups.

Dedicated research in forest monitoring requires specific expertise in fields such as forest mensuration, statistical survey sampling, statistical modelling, remote-sensing image processing, which usually requires time to accumulate. Establishing a research infrastructure and capacity-building process may, therefore, be considered part of the institutionalization of national forest monitoring (*Principle 4*) and should be closely linked to existing research institutions in the fields of forest management.

2.2 Scope principles

Principle 6: Participatory discussion process

National forest monitoring systems generate data and information on forests and trees at national level through a participatory discussion process among national stakeholders on the scope and objectives of forest monitoring. Such information is of interest to stakeholders outside the forestry sector, for example, in environment, agriculture, tourism and infrastructure development. In addition, both civil society and the private sector are likely to be interested in how forest and tree resources are managed.

Defining and reaching agreement on the scope and objectives of the national forest monitoring system is therefore crucial (Box 8). This process should involve all relevant groups in government, research and society. These groups first need to be identified. However, it may not be immediately obvious who they are and some may not have a powerful voice or be well connected to political decision-making. Such groups may include indigenous communities. Given that women and men use forests differently, it is also important to identify stakeholders representing the priorities of both sexes.

The scope and objectives of national forest monitoring can first be defined in terms of the expected outcomes and then broken down into more concrete elements (e.g. sectors to be involved in detailed planning and funding, variables to be recorded, responsibilities to be assigned, etc.).

Planning of the scope and objectives of the national forest monitoring system should be an inclusive process. While usually driven by experienced experts, it needs to be inclusive with interested parties not only welcome to contribute but actively invited to do so.

The scope and objectives may be adjusted from cycle to cycle, as may techniques and approaches. This must be achieved by maintaining methodological consistency while integrating emerging issues (*Principle 9: Flexible approach*), lessons learned and technological innovations.

Experience has shown that the most significant suggestions for adjustments are raised once the results of a monitoring cycle are presented and discussed: the presence and availability of concrete results frequently results in constructive discussions on improvements. This is because this point in the process clearly illustrates the scope and potential of a national forest monitoring system (NFMS).

Feasibility considerations must play an explicit role in the discussion and decision process on the scope and objectives. The scope can only be widened and objectives added once options have been identified to realistically implement the suggested additions, which includes identification of funding sources (*Principle 11: Feasibility including cost-efficiency*).

Principle 7: Satisfaction of national information needs

Information needs regarding national forest and tree resources are manifold. Accordingly, the consensus-oriented discussion process (*Principle 6*) prepares the ground for a comprehensive identification of priority information needs at the sub-national and national level, while efficiently supporting international reporting commitments.

Identification of information needs is usually an iterative process adjusted at the beginning of each cycle. While different sectors share some of the same information needs, each may have specific expectations. Other stakeholders may also use the information, for example, to track equitable access to forest benefits between men and women or between different social groups. Socio-economic dimensions, including sex-disaggregated data on forest use, may be of particular interest.

This identification process should be accompanied by an analysis of how *information needs* can be translated into *indicators* that can be observed feasibly during monitoring and used effectively to take decisions. While established observation and estimation techniques exist for many information needs (e.g. forest area, growing stock), this is not the case for information needs on other areas such as "forest biodiversity" or "naturalness of the forests". The translation of "information needs" into "observable indicator variables" will be partly a research issue and partly a political consensus

Box 8: Defining the information needs

Guiding the design of a national forest monitoring system is a demanding task. The incremental cost of adding single variables is frequently not great, which often results in the addition of many variables. It is common for forest inventories to collect data on more than 100 variables.

While many existing national forest monitoring systems collect data that are not immediately analysed and processed for national policy processes, these data are not necessarily useless. They could constitute an excellent basis for research and may prove important for future analyses (*Principle 9: Flexible approach*).

Information needs also evolve over time. For example, few forest inventory planners working on FAO inventories in the 1970s would have integrated information on forest use and further complicated implementation by adding interviews with forest owners and forest users. Today, such socio-economic data are considered extremely welcome and valuable.

process. At the end, however, an agreement is required and should be documented transparently.

Major data users, actors and interest groups should be consulted during this process, while keeping in mind feasibility in terms of costs and time related to implementation. It is helpful to analyse existing national forest monitoring systems in the region and invite experts to report on the possibilities and limitations of NFMS and the corresponding cost implications (*Principle 11*).

To prevent overloading of a national forest monitoring system it is useful to establish a distinction between "need-to-know" and "nice-to-know" data. While there will usually be little doubt regarding the integration of "need-to-know" data (core data needs are usually shared by several interested parties and financing is usually also straightforward), the integration of "nice-to-know" data will depend on solid justifications and cost trade-offs.

Box 9: Development and integration of emerging issues in national forest monitoring

Several national forest monitoring systems have developed, adjusted and integrated emerging issues. The terminology demonstrates such changes: while early forest inventories focused on assessment of the state of wood resources, these inventories were transformed into multi-purpose forest inventories, which integrated objectives other than wood production. Today, the considerably wider term "national forest monitoring" is used, which emphasizes the long-term character and the focus on trends.

Other emerging issues integrated into many recent national forest monitoring systems are trees outside forests and socio-economic variables.

Another example found in many countries relates to new requirements stemming from greenhouse gas accounting (or more specifically, carbon accounting) and biodiversity monitoring.

2.3 Design principles

Principle 8: Integration of and consistency with existing information sources

National forest monitoring should not be considered a stand-alone initiative, but in best case scenarios an undertaking that – within the scope of its particular mandate – interlinks with other national and sub-national initiatives that generate national level information. This requires compatibility with other information sources to the extent (technically and organizationally) possible. A careful analysis of the methods and definitions underlying the generation of such information is therefore necessary.

There is no general rule regarding which information sources should be used in national forest monitoring, either for data collection or the generation of information. For economic and technical optimization, national forest monitoring systems should make use of all available relevant information, bearing in mind the need to check for compatibility, accuracy and completeness.

Principle 9: Flexible approach

The technical and organizational design of a NFMS requires long-term efforts and must be able to integrate emerging issues and allow for periodic revisions, as these become necessary (Box 9). The origins of such emerging issues include changes in national policies, new issues brought up by international processes or new scientific findings. A flexible approach is thus an important element of the strategic and long-term orientation of national forest monitoring systems.

To date, the history of national forest monitoring has shown that integration is feasible under many different conditions and for various different issues. Integration, however, requires technical and organizational expertise, and above all, intensive communication between different interest groups.

Emerging issues cannot be taken into account during planning. As such, the technical design must be sufficiently flexible to allow for adjustments, and the organizational design must be able to adapt to changes.

Periodic revisions and adjustments may also be necessary, when national forest monitoring systems have to provide information to comply with emerging or changing international reporting obligations. It is essential that the concepts and definitions used are updated and made compatible with international processes.

Principle 10: Multi-purpose approach
Information and knowledge generated by national forest monitoring systems need to feed into and support national and international forest-related processes. In order to serve these processes national forest monitoring systems need to be multi-purpose. This is also a logical consequence of *Principle 3*, which stipulates a wider geographical scope. However, maintaining a multi-purpose approach also implies the integration of multiple thematic fields, such as biodiversity, carbon and the utilization of non-timber forest products. While national forest monitoring systems have the potential to integrate many more variables in a feasible manner, the multi-purpose orientation requires inter-sectoral communication and coordination. In the end, however, the multi-purpose approach may support the feasibility and cost-efficiency of national forest monitoring efforts, *(Principle 11)*, when the development of the design not only succeeds in integrating new issues from other sectors, but also in raising the corresponding co-funding.

Principle 11: Feasibility including cost-efficiency
Information provision including data collection, storage and analysis and operation of a permanently institutionalized forest-monitoring unit must be feasible and affordable, according to national circumstances. In the past, the lack of priority assigned to national forest monitoring has resulted in a lack of willingness on the part of governments to invest into long-term monitoring systems. Perhaps current international processes, where reliable national forest information plays an important role in monetary terms, will help to change this attitude.

Still, national forest monitoring needs to be feasible and follow approaches that are financially affordable. This principle refers to all other components addressed here, such as technical implementation, institutionalization or capacity building. The same principles hold true for national forest monitoring as for any other government expense: it needs to be technically justified and economically reasonable, and there must be a legal basis for the expenditure.

While a full-blown cost-benefit analysis is not possible (in the absence of to the ability to quantify in monetary terms the benefit of improved information), the guiding principle will be that defined objectives are achieved at minimum cost without compromising data precision, accuracy or quality.

2.4 Data principles

Principle 12: A well-defined data and information-sharing policy
Data and information produced by national forest monitoring systems are of interest to many different parties. They should be accessible to different users, either as original or as aggregated data sets. This does not necessarily mean that public access is granted to a database, but that a clear data sharing policy is formulated to which national and international interested parties can refer. This policy may, of course, contain restrictions in line with national interests and legislation. For example, in many cases it will be difficult to make geo-referenced data available for private forests.

In particular, research institutions will be highly interested in obtaining access to original or aggregated data.

Defining a data policy that regulates access to national forest monitoring data sets or sub-sets also means that long-term data storage and management need to be secured. This point relates directly to the institutionalization of NFM *(Principle 4)*, in particular the following three areas: (i) database structure (software) and physical databases (hardware), (ii) experts who know the database and how to access data and meta-data, and (iii) institution(s) where the database and experts are located.

2.5 Overall principles

Principle 13: Credibility through transparency and quality
The design and implementation of national forest monitoring systems are large undertakings that are methodologically complex, involve many actors and are accompanied by many interested parties. The overall goal is to maintain the credibility of the results. This implies that the results must be produced in a manner that is scientifically defensible, which means that each methodological and organizational step of the

approach needs to be fully and transparently documented and justified. This will include a comprehensive and critical analysis of all errors and implementation challenges.

The user of information products generated by the national forest monitoring system should be able to fully understand what has been reported and be able to assess the quality and credibility, based on complete and transparent documentation. This documentation should include definitions of the population, the variables and the precision requirements for the major target attributes, the elements that guide the design of the national forest monitoring system and other methodological elements required to demonstrate that the NFM is built on a sound scientific basis.

Quality also refers to precision and accuracy, information on uncertainties, and to the transparent management of errors and error sources. Any value should be accompanied, if possible and practicable, by its corresponding estimation error that provides information about the statistical reliability of the estimate.

Quality control measures applied within the NFMS should be implemented at all phases of the process and properly documented. This includes control measurements/check cruising, calibration of measurement devices, and continuous communication with and training of those who generate data and results (e.g. field teams, remote-sensing analysts and statistical analysts). Quality assurance, (i.e. checking some or all elements of the system by experts and/or institutions not directly involved in the process) may further increase both the quality and the credibility of the information produced by the NFMS.

There is no such thing as a general "best practice guide" for national forest monitoring and it is unlikely that one could be written in general terms. All national forest monitoring systems need to be developed based on specific country circumstances, such as natural conditions, infrastructure, institutional setting and available capacity. It is important that these conditions are spelled out clearly, completely and transparently.

Principle 13 and *Principle 8* are in accordance with the five reporting principles stipulated in the *IPCC Good Practice Guidance*: consistency, comparability, transparency, accuracy and completeness. While IPCC focuses explicitly on the reporting phase of carbon assessments, it is suggested here to apply *Principle 13* to the entire national forest monitoring process.

Principle 14: Collaboration at the international level

There are good examples of comprehensive experiences in all aspects of national forest monitoring at the international level. Collaboration in planning, implementing, analysing and ensuring the quality of different national forest monitoring systems constitutes an excellent means of knowledge exchange and avoiding common errors and pitfalls. In addition, it may also support national capacity building. International organizations and bilateral donors may be interested in supporting exchange of experiences, for example, through regional networks. Such international collaboration should be complemented by collaboration at the national level between all interested parties.

2.6 Cross-cutting issues

Issues such as gender and equity cut across all the principles. Most countries have policies on these areas, and national forest monitoring systems should take these into account. Table 2 summarizes typical entry points for these principles.

Table 2: Gender as a cross-cutting issue among some of the principles

Governance principles	
Principle 1: Country ownership and responsibility	Engage with the national ministry responsible for gender issues
Principle 2: Legal and policy basis	Include gender as a key information need as part of a wider socio-economic mandate
Principle 3: Landscape view	What are the different roles of women and men in shaping the landscape? What are the differences in how men and women depend on the landscape?
Principle 4: Institutionalization of NFM	Structures should welcome women as well as men, especially in professional and decision-making positions
Scope principles	
Principle 6: Participatory discussion process	Include civil society and other grassroots women's organizations, as well as government authorities related with gender
Principle 7: Satisfaction of national information needs	Include sex-disaggregated data on forest use and socio-economic information
Design principles	
Principle 9: Flexible approach	Social sectors may want to use the data to understand issues of equity and to plan interventions
Data principles	
Principle 12: A well-defined data and information-sharing policy	Publicly available information promotes more equitable access to forest resources

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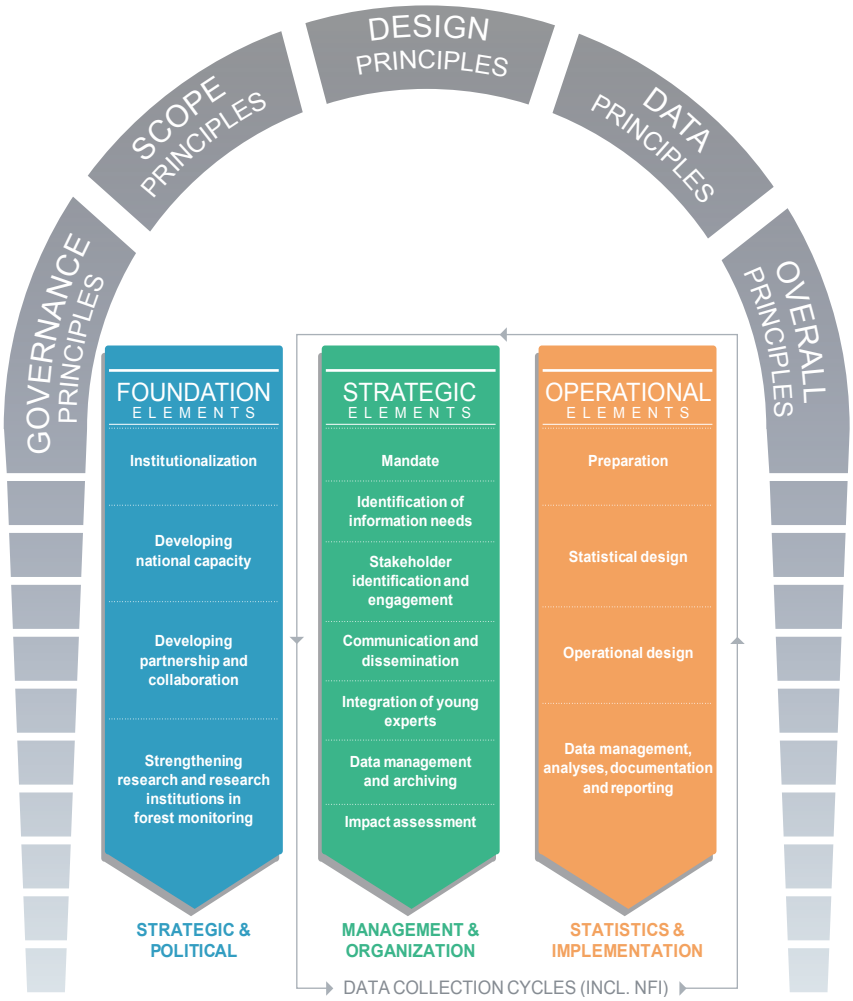

Figure 2: Core elements in a NFMS and the general relationship between NFMS and data collection cycles

Figure 2 provides a schematic overview of the components that constitute a comprehensive NFMS. This is followed by guidelines on the following basic elements that comprise a NFMS:

Foundation elements refer to the organizational and technical framework conditions within which a NFMS is implemented. They include activities such as the institutionalization of the NFMS, the development of national capacity and the strengthening of national forest research institutions in the field of forest monitoring, as well as the establishment of national and international partnerships. These activities prepare the ground for subsequent technical implementation work. As such, they require careful planning and sufficient time and cannot be tackled at short notice. If carefully prepared, the foundation elements will play a key role in ensuring the operation and sustainability of the forest monitoring system.

Strategic elements refer to organizational and planning actions for data collection activities within a national forest monitoring system. They do not include specific scientific-technical issues. These actions include: the definition of goals, products and variables based on inquiries about information needs; project planning including assignment of responsibilities; networking; the provision of information technology, satellite imagery, measurement devices, means of transport and communication; and recruitment, contractual issues and other matters related to human resources.

Operational elements refer to actions for the optimization and definition of technical design elements of field and remote-sensing data collection and analysis, and the use of auxiliary information including approaches for quality assurance and control, the preparation and implementation of data acquisition and, eventually, focused reporting to specific target groups.

Part B

Guidelines

The following sections address technical issues related to implementation based on the principles introduced in Section 2. They present a variety of planning issues some of which are technical in nature, while others are organizational or strategic. The overall aim is to provide detailed and comprehensive guidance; however, it should be noted that not all the points addressed here are equally relevant under all national circumstances. The specific goals or framework conditions of different national forest monitoring systems (NFMS) may focus more on some elements and less on others.

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Section 3

Foundation elements

The foundation elements prepare the ground for efficient planning and implementation of a forest monitoring system as a long-term undertaking. They can be grouped under four themes: (i) institutionalization; (ii) developing national capacity; (iii) developing partnerships and collaboration; and (iv) strengthening research and research institutions. These themes are interlinked and some may be pursued simultaneously.

Preparing foundation elements can be a time-consuming and lengthy process. This does not mean, however, that the technical planning and implementation of data collection activities for an initial national forest assessment should be postponed until all foundation elements are in place. Where possible, this work may start immediately while the foundation elements are prepared in parallel – and in close association – using a step-by-step approach, with a view to establishing a sustainable and permanent system.

3.1 Institutionalization

Institutionalization means that the NFMS is formally, firmly and permanently embedded within an administration – usually the forest administration – of a country. Because a NFMS is a long-term endeavour, a legal basis, financial commitment and a permanent institutional framework are vital to ensure efficient implementation and operation.

Only a permanently institutionalized NFMS can help ensure that: (i) national monitoring of forests is considered an important government responsibility; (ii) data and information are consistently collected, managed, made permanently available and analysed over time (assessment of changes); (iii) national expertise is accumulated and further developed, which is a precondition for further development and improvement of the system; (iv) the government has a clear contact point when analyses and specific forest information are needed; and (v) the expertise and experience developed is retained and creates the necessary "institutional memory". All of these contribute to enhancing the credibility of forest-related reporting at the national level.

Essentially, the institutionalization of a NFMS in a country shall address the following aspects:

a. Efficiently integrate the NFMS and its activities (what will be done and produced, by whom, when, and with what resources, etc.) into existing national frameworks regarding policies and legislation, and into government structures (organizations) and financing systems (e.g. national budget). This integration will create the legal justification and formal basis for the long-term functioning of the NFMS. It is also a clearly visible expression of full national ownership.
b. Ensure the provision of funds via sustainable/appropriate finance mechanisms for the implementation and continuation of the NFMS, with a view to guaranteeing up-to-date information at regular intervals.
c. Formally assign, through legal instruments, clear mandates for the collection, management and analysis of data, and for the delivery of specific products and services to an organization or network of organizations, such as a government agency, research organization or academic institution. The mandate assigned to such organizations should include a clear purpose as well as short and long-term goals of the NFMS. It may be necessary and reasonable to create a new organizational unit or to create a new section within an existing organizational unit to provide the appropriate infrastructure and means.
d. Indicate (and, ideally, formally endorse) appropriate coordination mechanisms by which overall management, data collection, management and sharing among units and possibly the public, ministries and other organizations (private and public) will take place.

e. Take into consideration lessons learned from previous/existing experiences of national institutionalization processes, and possibly relevant cases from outside the country.

These institutionalization activities relate to: *Principle 1: Country ownership and responsibility, Principle 2: Legal and policy basis, Principle 4: National Forest Monitoring should be institutionalized and Principle 11: Feasibility including cost-efficiency.*

3.2 Developing national capacity

National ownership and sustainability of the NFMS depend on institutional capacities to meet the forest information needs of users. This calls for continuous strengthening of human capacities in the technical fields of forest monitoring, programme management, administration and operation.

The NFMS should ensure that person(s) responsible for implementation have the appropriate level of education and the necessary knowledge and experience. In order to develop and sustain national capacity to maintain the NFMS, in particular, technical capacity in remote sensing, field measurements, data processing, information management and communication techniques, the NFMS shall:

a. Identify the existing capacities and assets of staff performing these tasks, and identify gaps and training needs based on the institutional mandate. This should include both scientific-technical and socio-economic capacities.
b. Prepare a capacity-development strategy building on the identified capacity development needs and gaps. The strategy should adopt a stepwise and continuous learning approach and should involve academic institutions, as appropriate.
c. Cooperate with academic institutions by supporting the development or adjustment of curricula relevant for the NFMS.
d. Promote the integration of student exchange programmes and student labs into forest monitoring fieldwork or remote-sensing lab work, among other tasks, and promote the short-term employment of young professionals through internships and early career positions (see also Section 4.5).
e. Promote the use of NFMS data sets for research and innovation in all forest-related fields.
f. Strengthen linkages with other national, regional and global institutes by sharing lessons learned through various mechanisms, such as south-south cooperation (see Section 3.3).

These activities relate to *Principle 5: Research infrastructure and capacity building.*

3.3 Developing partnerships and collaboration

Nearly all forested regions can point to successful examples of national-level or sub-national forest assessment. More and more countries are implementing full national forest monitoring systems, providing excellent opportunities for international and regional collaboration and the sharing of experiences regarding planning, implementation, analyses, capacity building, technical expertise and lessons learned – both success stories and failures.

Networks may be actively developed in all fields relevant to forest monitoring.

Based on the above, a NFMS shall:

a. Promote and establish partnerships in fields relevant to the NFMS. These partnerships may extend to specialized national and international institutions and to international networks and programmes. They should be designed in a manner that ensures clear and agreed responsibilities and accountability among all partners.
b. Promote agreements between partners with respect to intellectual property when specific activities are addressed that may generate material subject to copyright, patents or other intellectual property jurisdiction, such as publications.
c. Promote intersectoral coordination within the country. It is likely that sectors such as agriculture, environmental protection, biodiversity conservation, ecotourism development and other social fields will be interested in the results of national forest monitoring. The design of the NFMS is

frequently such that additional variables or target resources can feasibly be integrated. This may lead not only to greater added value at the national level, but also to greater understanding, acceptance (and support) of the monitoring results and the NFMS programme itself. The goal of strategies to nationally embed a NFMS should be to work towards a collaborative working relationship with other national agencies, rather than a competitive one.

Development of partnership and collaboration relates to *Principle 1: Country ownership and responsibility, Principle 9: Flexible approach, Principle 10: Multi-purpose approach and Principle 14: Collaboration at the international level.*

3.4 Strengthening research and research institutions in forest monitoring

Planning and successful long-term implementation of an NFMS requires accompanying research in all cases, although to a varying degree. Generic research questions include how to optimize technical design elements of forest inventories, the development of locally specific models to predict biomass or carbon stocks, and the development of optimal remote-sensing analysis approaches.

In addition, the data generated by a NFMS offer manifold opportunities for research beyond the specific field of forest monitoring. There is a clear need to build capacity to identify priorities for forestry research based on stakeholder needs, with a view to strengthening existing institutions and creating new ones where necessary. NFMS-related activities in the context of strengthening research and research institutions in forest monitoring shall:

a. Ensure that the flow of information between the NFMS and researchers is reciprocal: research objectives should be clearly defined by the NFMS, but flexible enough to permit the incorporation of new research results and improvements to the NFMS.
b. Identify scientific research needs to fill existing information gaps, specifying research priorities and providing certain basic facilities to facilitate progress, enabling the researcher to lead the NFMS into new areas of development.
c. Promote collaboration with different research units, where possible, with the goal of enhancing implementation and fostering the sustainability of the NFMS. In this context, research collaboration with universities can encourage young scientists to become interested or even enthusiastic about forest monitoring. Strengthening research, therefore, has direct links with "capacity development" (see Section 3.2).
d. Promote networking and collaboration among national, regional and international research institutions and actors to ensure adequate channels for the dissemination of results.

The strengthening of forest monitoring-related research relates to *Principle 5: Research infrastructure and capacity building and Principle 9: Flexible approach.*


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Section 4

Strategic elements

Strategic elements must be considered during preparation and implementation of a national forest monitoring programme. These elements define the course of the NFMS as well as specific issues in terms of "how" and "who" without addressing detailed technical-scientific aspects, which are dealt with under *Operational elements* (see Section 5). This section covers issues relating to the mandate of the NFMS, assessment of information needs, definition of the desired output, participatory approaches, management of information, dissemination of findings and planning for an impact assessment.

Strategic elements should ideally be reviewed periodically to ensure that they still apply to the current (and anticipated future) needs of the NFMS. If an adjustment is required, the NFMS can be modified accordingly. The NFMS should not be perceived as a static system, but should rather confront evolving issues and integrate new components and technological advances wherever sensible and feasible. However, it is important to maintain consistency over time to maintain the capacity to estimate changes and establish time series for relevant variables and topics.

4.1 Mandate

The implementation of a NFMS requires a clear political mandate, which can only be issued by a government body. Mandates also usually imply the definition of a vision, goals, targets and available resources, including budget, personnel and infrastructure among others. In some cases, legal regulations are also necessary, for example, to facilitate access to private land to conduct field inventories.

The NFMS mandate shall include:

a. The scope, goals and targets of the NFMS, which should be specific and measurable – covering both the short and long-term.
b. A clear designation of responsibilities and functions for all entities involved in achieving the objectives and targets of the NFMS, with normally a single principal coordinating entity.
c. If the NFMS is implemented in a decentralized manner, a principal entity can harmonize, coordinate and maintain consistency between decentralized entities.
d. Explicit commitments to impartiality, freedom from undue influence or potential conflicts of interest that may lead to biased/compromised results.
e. Specification of the means, including resources (human, financing, infrastructure etc) for implementing the NFMS.

The mandate should provide the justification for a NFMS and relates to *Principle 2: Legal and policy bases* and *Principle 4: Institutionalization of NFM.*

4.2 Identification of information needs

The NFMS should be demand-driven in line with a clearly stated and formally mandated mission. Its objective should be to produce the best possible information within the given resource constraints. An information needs assessment process is a key step in identifying which information the NFMS should produce on a regular basis.

Once current and prospective information needs are known, the design of the NFMS can be defined (or revised) by the responsible government entity, while involving relevant stakeholders at each main step of the process. The results of the information needs assessment are used to determine and prioritize the data to be collected.

While this is an essential step, a balance needs to be found between a purely prescriptive, technically driven approach and a fully participatory approach involving all partners

(those with a vested interested in the NFMS) and other stakeholders (potential data users), as well as a balance between required information and available resources/capacities. If technical experts specify information needs without stakeholder participation, the resulting monitoring systems may be technically solid but will likely fail to meet stakeholders' needs. Conversely, information needs assessments with broad and open participation tend to result in extensive and unspecific wish lists of data, the collection of which is not feasible.

Information needs assessments thus need to be managed to ensure that the results are oriented towards the strategic information needs of governments and other stakeholders, while focusing on essential information that can feasibly be covered by the monitoring system. Experience shows that stakeholders in many countries have similar basic information needs related to forests and trees. Accordingly, experiences from similar countries can provide useful inputs to information needs assessments.

For the information needs assessment process, the NFMS shall:

a. Compile and take into consideration "key topics" derived from strategic goals and targets set by key forest and other natural resource, environment, land-use and development policies of the country, and from forest-related international policy commitments and reporting requirements (e.g. UNFCCC, CBD, FRA, SDGs, C&I processes).
b. Document how the key topics were selected or rejected.
c. Identify the "target area of reference". Information needs may refer to the national level, to the sub-national level or to other areas of reference. Stakeholders may mistakenly expect a NFMS to meet all forest management planning information needs for small areas. An information needs assessment is therefore a good opportunity to clarify the respective opportunities and limitations of monitoring small areas and the related technical challenges (as well as discuss estimations for rare events or variables not usually assessed in NFMS).
d. Identify the "target objects" to which the information needs refer.
e. Identify concrete forest monitoring-related questions for each of the key topics.
f. Define the expected format and type of output produced at the end of the analysis, for example, by elaborating tables, graphs and relationships between variables. The more concretely these information needs are formulated, the more easily they can be translated into measurable variables and data collection procedures by inventory planners.
g. Provide an opportunity for stakeholders representing different levels and sectors, including from indigenous groups/local communities and women's groups, to freely express their information needs and potential concerns in a participatory manner, so that strategic goals and targets can be clearly addressed.
h. Specify the precision/accuracy requirements (or expectations) in quantitative terms for key expected results.
i. Prioritize information needs to help address budget and precision constraints during the technical implementation process.
j. Make a clear distinction between "must-know" and "would be nice to know" information needs, especially where the latter may be of interest for research or address expected upcoming information needs. Clearly state the justification for the specific choices.
k. Provide a compilation of information needs in a manner that can be easily translated into variables, which can then be operationally observed through an accessible data source. This will form part of the technical design planning of the NFMS (see Section 5).

The information needs assessment identifies the desired output or "*what*" in a NFMS strategy and relates to *Principles 3: Landscape view, Principle 6: Participatory discussion process, Principle 7: Satisfaction of national level of information needs, Principle 8: Integration and consistency with existing information, Principle 9: Flexible approach and Principle 10: Multi-purpose approach.*

Box 10: Stakeholder identification

The organization leading the NFMS process is responsible for stakeholder identification. However, the list of stakeholders should be validated during the information needs assessment phase.

In this context, a stakeholder analysis implies a review of all possible partners/organizations in the country using forest information, either direct or indirectly.

4.3 Stakeholder identification and engagement

The involvement of stakeholders may extend far beyond expectations stated during the information needs assessment. Depending on their interest and expectations, representatives of stakeholders' groups may be invited to or integrated into the strategic or technical planning of the NFMS.

Such integration will promote acceptance of the NFMS as a whole, support decision-making on the various components of the system in line with identified information needs, help avoid misinterpretation of these information needs, and eventually reduce criticism when data retroactively identified as important are not gathered or made available. While the latter is a common situation (many good ideas occur only once results from NFM are presented), it is advisable to reduce this phenomenon to a minimum.

Strong participation and engagement of stakeholders groups is key to the overall success of a NFMS and contributes considerably to creating national ownership. However, in some cases the main constraint on genuine and proactive participation is a lack of political will to support the NFMS process.

To ensure the efficient participation of different stakeholders, a NFMS shall:

a. Conduct a stakeholder analysis to identify partners and other stakeholders willing to participate in the NFM process, including different national institutions (especially those involved in forest-related policies and land management), the private sector, academia, civil society, women's and minority groups (including indigenous groups) and communities who depend on forests for their livelihoods. The stakeholder identification and engagement process should be transparent and clarify the intentions of the various stakeholder groups willing to participate in the NFM.
b. Encourage top decision-makers and planners to incorporate participation in the NFMS process in their plans and programmes. In particular, it is mandatory to involve other sectors (agriculture or urban development) when an information needs assessment identifies a need to inventory lands that fall outside the mandate of the forest administration.
c. Stimulate the cross-sectoral participation of academia and research institutes.
d. Reinforce the capacities and knowledge of stakeholders on the benefits and use of a NFMS and the resulting information.
e. Promote the creation of an institutional working group or technical advisory and consultative committees, which the NFMS should report to annually regarding activities.

Fostering stakeholder participation provides a response to the questions "with whom" and "for whom" in a NFMS strategy and relates to *Principle 1: Country ownership and responsibility, Principle 3: Landscape view, Principle 6: Participatory discussion process, Principle 7: National level information needs, Principle 9: Flexible approach and Principle 14: International collaboration.*

4.4 Communication and dissemination

Proactive communication and dissemination is crucial to ensure that potentially interested stakeholders are adequately aware of the existence of the NFMS and its related activities, thereby facilitating access to the results produced and the methodologies applied whenever needed.

To guarantee strong communication and dissemination, a NFMS shall:

a. Plan for efficient internal communication between the various actors and processes of the NFMS. This is important for the smooth functioning of the process and also supports quality assurance.
b. Ensure that all who participate in different aspects of the NFMS understand why their contribution to the system is so important.
c. Develop a strategy to respond to enquiries from external interested parties, including the interested public, NGOs and journalists.
d. Promote the use of social media and build a website to disseminate, communicate and share documents, publications or data.
e. Promote networking with other NFMS in neighbouring countries or regions to share experiences.
f. Secure the services of a communication officer to deal with these enquiries professionally and to issue information bulletins or press releases.

Communication and dissemination is crucial for any NFMS as it promotes *Principle 6: Participatory discussion process* and *Principle 13: Credibility through transparency and quality.*

4.5 Integration of young experts

National forest monitoring programmes are complex multi and trans-disciplinary undertakings in which numerous professionals from different academic backgrounds with different technical skills collaborate closely with the assistance of numerous helpers.

Accordingly, NFMS offer excellent vocational training and educational opportunities for students and young experts in the early stages of their careers. They can engage in various functions to further develop their knowledge and expertise not only of national forest monitoring, but also of the forest resources of their country.

The integration of young experts – both female and male – within the planning and organization of a NFMS is closely linked to capacity development and networking. In this regard, a NFMS shall:

a. Promote the participation of young experts in the NFMS wherever possible, for example, by involving national undergraduate, graduated and post graduate students in data collection and analysis;
b. Promote quality internships within education, training and employment schemes through collaboration with research groups and universities;
c. Promote coaching methods for young experts.

The "Integration of young experts" component contributes to the question "who" in a NFMS strategy and relates mainly to *Principle 5: Research infrastructure and capacity building.*

4.6 Data management and archiving

The immediate outcome of a NFMS is data, either collected in the field or obtained using remote-sensing data sources at specified intervals, from which targeted information regarding the current status and changes is derived for decision-making purposes. Provision need to be made for long-term data management to allow analyses to be repeated and time series to be built from inventories at earlier points in time.

It is, therefore, recommended to incorporate comprehensive data management into the design of a NFMS from the outset. Such a data management system is ideally located within the permanent institution responsible for the NFMS, in order to guarantee long-term preservation and availability of data both for standard analyses and upcoming research questions.

Policies on sharing data must also be developed. Special consideration must be given to sensitive data, such as personally identifiable information (PII) and plots that may be located on private grounds. If actual coordinates are known, then data users could possibly query the data for valuable trees or invasive species and visit the plot to harvest the trees or remove the invasive species. Hence, consideration should be given to providing only approximate locations and restricting the dissemination of actual coordinates to the analysts concerned, or to

making publicly accessible only aggregated data.

Accordingly, a good data management system for a NFMS shall take into account the following points, which are common for data management systems:

a. Have a well-documented data set with associated metadata, a complete and well-defined protocol for data archiving and preservation including storage and backup, and a long-term vision to ensure data storage technologies remain up-to-date and data remains retrievable in the event that operating systems and data storage systems change.
b. Include a security protocol with a description of technical and procedural protections for information, including confidential information, and details of how permissions, restrictions and embargoes will be enforced.
c. Define a data policy that describes which data may be shared and how (free and available, available upon request, restricted) including access procedures, embargo periods (if any), technical mechanisms for dissemination and exchange formats. In cases where some parts of a data set cannot be shared, the reasons for this should be specified (e.g. ethical, personal data rules, intellectual property, commercial, privacy-related, security-related). This decision regarding which data sets to make publicly accessible and which to provide more restricted access to is dependent on national legislation, strategies and policies.
d. Define how and where data will be stored, indicating in particular the type of repository (institutional, standard repository for the discipline, etc.) and the institution(s) responsible for storing and archiving the data. Depending on the general national strategy for storing national statistics, there may be institutions prepared to integrate the NFMS data sets as standard national data sets generated at regular intervals. This would underline the general information character of the data generated by the NFMS.

The data management system is an important component of a NFMS and is linked to various principles laid out in these guidelines. If opens access to data and results can be granted, it relates to *Principle 12: A well-defined data and information sharing policy*. If integrated with existing available information, it relates to *Principle 8: Integration of and consistency with existing information sources.*

4.7 Impact assessment

National forest monitoring systems are dynamic systems that require continuous development in line with new scientific findings on data collection strategies, evolving information needs and new forest-related policies. An important component of this development is the capacity to learn lessons from the NFMS during the implementation process and after its conclusion.

Although not a standard component of NFMS as yet, it is recommended to plan a systematic impact assessment of the process itself. This helps to streamline improvement of the NFMS and to analyse its overall usefulness.

Regarding developing strategies for an impact assessment, a NFMS shall:

a. Analyse who is using which NFMS results and for what purpose. A logical expectation would be that stakeholders who expressed specific information needs during the planning process could then demonstrate the ends for which they are utilizing the results. The analysis may also reveal gaps and new information needs that can be taken into account during the next data collection phase.
b. Review whether the stakeholders are satisfied with the data produced to address the original data needs, and analyse with them the inclusion of new variables or eliminate others that are not useful.

The impact assessment relates to *Principle 7: Satisfaction of national information needs, Principle 9: Flexible approach, Principle 10: Multi-purpose approach* and *Principle 11: Feasibility including cost-efficiency.*

Section 5

Operational elements

In order to meet the technical goals of a NFMS, it is necessary to define complex data acquisition and analysis strategies that will eventually lead to the desired products. These operational elements consist principally of the design of measurements and observations, the efficient integration of different data sources and up-to-date methodological analyses.

As in most complex projects, two major guiding criteria need to be considered when planning these operational elements:

1. The approach must be methodologically sound and enable the production of scientifically defensible products with an acceptable level of precision – that are therefore overall credible – in accordance with the defined objectives. This corresponds mainly to *Principle 13: Credibility through transparency and quality*.
2. The approach must be operationally feasible in terms of the available resources: this refers to the time frame, the available financial resources and expertise/human resources, and the expected outcome/results of the NFMS. This corresponds mainly to *Principle 11: Feasibility including cost-efficiency*.

There is of course a trade-off between these two criteria and an efficient compromise will need to be found for each NFMS.

An optimal data acquisition design is sought for each well-identified individual objective (e.g. finding an optimal sample size as a function of the demanded level of precision of estimation. However, real-life forest inventories are frequently determined by the available resources, which are usually fixed. An efficient compromise between these two criteria therefore needs to establish the best allocation of resources to the different methodological components, so as to ensure the defined set of objectives are met, to the extent possible (Box 11).

Box 11: An optimal solution?

There is no one optimal solution for national forest monitoring systems, but instead various good solutions. The decision in favour of one approach or the other is frequently based on good experiences and successful implementation in other cases.

In this context, the goal is to produce data and information of the highest quality, which means reducing errors and their effects of all kinds. As in any empirical study, errors cannot be entirely avoided. However, every planning step should attempt to minimize errors to the extent possible. This is not only a matter of statistical design (e.g. sample size considerations), but also a matter of training (keeping measurement errors low and ensuring that the inventory protocol is followed), regular and focused controls, and accompanying research that produces, for example, specific biomass models that fit the conditions of the country.

The operational elements of a NFMS mean that all methodological details which refer to data acquisition, analysis and reporting, also include the respective institutional, organizational and logistical aspects.

To avoid confusion and repeated adjustments to the approaches, all methodological details and procedures must be unambiguously defined and documented before data gathering campaigns start.

When planning operational elements, it is also important to take in consideration and build on existing experiences, where feasible.

The treatment of operational elements is subdivided here into sections on preparatory activities, statistical design for field sampling and remote-sensing integration, operational planning to implement this design, and data management, analysis, documentation and reporting.

5.1 Preparation

The preparatory steps of the NFMS design focus on the operational and target-oriented definition of terms, the identification of variables to be observed to meet information needs and their subsequent prioritization, the definition of data sources to be accessed to observe these variables including available information, and the assessment of available expertise and other country resources.

This process may also identify potential uncertainties and problems facing implementation, as well as potential solutions. A key element of the preparation phase is the development of a realistic technical design plan that will allow technical and logistical implementation of the data gathering campaign, with a view to fulfilling all (or at least priority) information needs within the allocated budget.

This component relates to *Principle 3: Landscape view, Principle 6: Participatory discussion process, Principle 8: Integration of* and *consistency with existing information sources and Principle 12: A well-defined data and information sharing policy.*

5.1.1 Population of interest and sampling frame

Defining the population of interest refers not only to the numerous and different definitions of "forest", but also to questions such as whether to explicitly include other land uses (e.g. assessment of the complete tree resources of a country would include trees outside the forest), whether all forest types and ownerships should be considered, and whether land-use changes and the monitoring of land use after conversions should be monitored or not.

In this context, a NFMS shall:

a. Clearly define the population of interest and – wherever possible – provide maps showing which sub-national areas are included and which are excluded. This population will be the subject of the forest monitoring and the subsequent results.
b. Ensure that the definition of "population" is in line with the identified information needs. This may include considerations of the minimum tree or forest size to be surveyed. For example, in forest surveys it is usually neither possible nor necessary to record the diameter and height of all tree individuals. However, it is very important to consistently apply a threshold above which all trees should be measured and recorded. Depending on the forests to be surveyed, this threshold may change from strata to strata. For example, lower thresholds may be applied to rather open savannah-type forests with smaller trees and bushes, and higher thresholds to closed rainforests. In defining the thresholds, it is also important to consider the potential effects on estimates of measurements and changes for both trees and forests.
c. Try to ensure that most of the population is accessible for ground measurement, so as to minimize the risk of non-responses. In other words, aim to ensure that the sampling frame is as close as possible to the population of interest.
d. Explicitly clarify those areas where ground data acquisition is not possible, meaning that the sampling frame is smaller than the population of interest. This limitation commonly refers to field observations where problems of access may be prohibitive, for example, due to security reasons, whereas remote sensing may often cover the entire national territory.

5.1.2 Identification and specification of variables to be recorded

The information needs assessment will produce a ranked list of data requirements that key stakeholders would like to obtain. Usually, this list contains variables that can be observed or estimated (e.g. forest area or tree species), as well as characteristics that need to be broken down into measureable variables or indicators. For example, when data on characteristics such as "forest biodiversity", "forest structure" or "sustainability of forest utilization" are among the products of a NFMS, clear definitions need to be established, as well as an indicator-based model, so as to allow the required indicator variables to be recorded. The translation of information needs into sets of measurable variables is an extremely important preparatory

step that may require collaboration between the stakeholders who expressed these information needs and experts, in order to identify suitable indicators that can feasibly be integrated into a NFMS. This feasibility is also a function of priorities and cost.

To enable the identification and specification of variables, a NFMS shall:

a. Translate the information needs into measurable variables (including variables for which classes or types can be assigned such as tree species or land-use types).
b. Clearly and explicitly define all variables, both in terms of their subject matter and in terms of their observation or measurement. For metric variables (e.g. "tree height") measurement device(s) used also need to be defined. If a variable is nominal (e.g. the variable "forest type"), all possible names need to be listed (including the "name": unknown), and if a variable is categorical (e.g. the variable "tree vitality"), all categories shall be defined unambiguously.
c. Document all defined elements and use them later as the basis for the elaboration of a comprehensive field manual.
d. For some target variables that cannot be directly measured or observed, include variables such as stem volume, tree biomass or carbon. For these variables, proxy approaches need to be defined, usually via models. The topic of statistical models is dealt with in more detail in Section 5.2.
e. Determine which data sources are to be used based on the variables to be recorded, where the main sources are commonly sample-based field observations and remote sensing. However, depending on the information needs, interviews with forest owners, forest users, the forest service or ministries may be envisaged and planned for.
f. Be consistent with national and international standards to foster comparability.
g. Use consistent methods over time to enable estimation of change. Changes in definitions, with respect to repeated data collections, shall only be done for very good reasons and without compromising the comparability of methods or the possibility to reliably estimate changes of the priority target variables. Avoiding changes thus requires care in completing definitions.

5.1.3 Review of existing data and information

As with planning for any complex project, readily available existing information should be taken into consideration as long as its origin is transparently documented and it meets the expected quality standards.

"Existing information" refers here to all types of information useful or required for forest monitoring, and may include technical information sources (e.g. forest inventory data and results at national, sub-national or local level; existing models for the prediction of non-measureable variables such as volume, biomass and carbon; topographic and thematic maps; remote-sensing data, etc.). Information on road infrastructure is also relevant, especially regarding seasonal accessibility.

However, "existing information" also refers to the availability of information about contact persons in provincial or local forest offices, who may be able to provide information about risks of access in certain regions and also facilitate fieldwork planning. In addition, they may possess information about potential local helpers in different regions of the inventory area and inventory staff who undertook different tasks in prior inventory studies.

Of course, existing information is only helpful when it is up-to-date and can be verified for quality.

When compiling existing information to support the NMFS, the following points shall be considered:

a. Identify which of the expressed information needs can be addressed by using existing information;
b. Take into consideration national and international sources that may provide pieces of existing information, including maps and local forest inventories;
c. Identify and prioritize information gaps, such as missing, incomplete, out-of-date or imprecise variables, and evaluate whether or not it is worth collecting additional data to fill the information gaps;

Box 12: Uncertainty

Uncertainty is an important concept in empirical studies, including forest monitoring.

It is a good practice to accompany all estimates with a precision statement to give the reader a sense of the reliability of the estimates, for example, "the carbon stocks per hectare are an estimated 150 Mg/ha with a 95% confidence interval of +/-5%".

A "high" level of uncertainty will compromise the credibility of the presented results. The aim is therefore to attain sufficiently high levels of certainty.

Target precision levels are commonly defined along general precision levels such as 5% or 10%, and are based largely on experiences and traditions.

d. Provide useful information to better plan the process of data collection (e.g. rainy seasons, land accessibility, social conflicts, conflicting activities, course to plot, etc.).

5.1.4 Uncertainty levels for the expected products

A further outcome of the information needs assessment is the possibility to more specifically define the desired level of precision for the estimators from sample-derived results or the accuracy of remote-sensing-based classifications. It is important to take these expectations into account, as they may have an influence on the design, for example, of sample-based field inventories (sample size and plot design) or remote-sensing analyses (classification and accuracy assessment).

Often, however, it is extremely difficult to define "suitable", "acceptable" or "practicable" precision levels for sample-based estimates and accuracy levels for remote-sensing classification products. This is the result of a variety of factors. First, the threshold for "minimum precision requirements" for the estimators to be analysed on a national-level forest inventories has not been scientifically studied and has therefore not been defined. There are no general recommendations outlining the required precision of estimates (e.g. of forest area, biomass stocks or intensity of illegal logging) to best serve the needs of policy decision-makers or stakeholders.

The common approach is then to work with general orders of magnitude such as 5% or 10%. Furthermore, stakeholders may not understand the concept and specific meaning of "statistical precision of estimation". It then becomes difficult to make informed statements about precision requirements. In this context, the level of desirable uncertainty (Box 12) associated with precision is often set *a priori*.

Minimum precision requirements are usually formulated for only a limited set of priority target variables. These variables must be identified and justified. Optimization of the sampling and plot design and the use of remote sensing data is often guided by precision considerations on one or two variables, for example, "basal area" (or related variables such as volume stocks or biomass stocks) and "forest area", both of which are typically among the core variables in forest monitoring.

Box 13 describes the basic relationship between statistical precision and sample size for sampling studies such as field inventories, where "sample size" may be taken as a direct proxy for "cost". Some studies set recommendations regarding minimum *sampling intensity* to achieve precision goals (e.g. "the fixed area sample shall cover at least 5% of the forest area"). Such approaches are not generally recommended, as there is no clear relationship between precision and sampling intensity when using sample plots in systems such as a forest inventory. Instead, it is recommended to focus on sample size (taking plot size into consideration). In fact, one of the great challenges of national forest monitoring is to explain to non-experts that high statistical precision may be achieved even when sampling intensity is low. A sample size of n=5000, for example, may allow estimates of forest area and growing stock at the national level with confidence intervals of +/- 1% or less, although the sampling intensity may be in the order of just 0.001%. Experience also shows that having to measure only a limited number of trees improves fieldwork motivation, which also helps to keep measurement error at a low level.

Care also needs to be taken with respect to the precision on the estimates on forest changes

Box 13: Precision

In statistical sampling, the primary factor driving precision is the within-population variability. One way to compensates it, is increasing sample size.

Increasing precision will have repercussions on the resources required. For example, in simple random sampling and other sampling designs, an improvement in precision by a factor of f (e.g. f=2 for a reduction of 10% to 5%) requires an f^2 fold sample size (in this example, four-fold) and, therefore, approximately f^2 times as many resources.

parameters. Overall, these changes might be small, but may be large relative to the estimation method. For example, if the tree diameter increment of a single tree over a five-year long period is 20 mm, and the estimation of the diameter itself (considering where on the tree it is measured, at which part of the tree, etc.) is not sufficiently precise, this may affect the final value when the confidence interval is reported. In addition, whereas sampling intensity may provide precise estimates for land use for one point in time, the same sampling intensity may not be able to estimate land-use change within acceptable levels, depending on the size, types and distribution of the land-use changes that occur in a country.

When specifying the target precision of estimations, the following points shall be taken into account:

a. Precision also involves error sources, which differ from sampling-related errors, and should also be taken into account.
b. The NFMS should have a direct correspondence with the information needs assessment.
c. The priority variables and their precision requirements should be clearly defined.
d. NFMS preparation must integrate the relationship between costs and precision and make sure that this is clearly understood by stakeholders who express precision requirements and those who design the inventory, so as to avoid unrealistic expectations.
e. The NFMS should integrate "precision of estimations" into training and capacity building of technical staff as a key topic, as well as into communications with stakeholders and parties interested in the results.

5.1.5 Assessment and optimization of available expertise and human resources development

Implementation of a NFMS will require the identification and services of experts from various disciplines and expertise, including – but not necessarily limited to – project managers, inventory statisticians, statistical modellers, botanists, taxonomists, dendrologists, biometricians, and specialists in remote sensing, GIS, socio-economics, and data and information systems management. These specialists need to be assigned to teams that adequately address the necessary monitoring tasks. Not all required expertise may be readily available within government institutions. Accordingly, expertise and support may be sought through cooperation or requests for external collaboration and partnership.

Knowledge exchange and collaboration between countries are an efficient means to enhance in-country capacities in specific technical fields. Creating networks of technical experts who transfer their knowledge and share their experiences can prove beneficial to monitoring the progress of available national and regional capacities. However, as mentioned above, these short-term training measures should be accompanied by a long-term capacity development strategy that targets national students and assists them to specialize in disciplines relevant to forest monitoring.

In order to assess the available expertise in the country, the NFMS shall:

a. Identify the expertise needed for the NFMS and the current available expertise. This could be achieved- for example, by issuing public announcements of positions in the NFMS and consulting with national forest monitoring experts through their networks.
b. Develop networks of expertise across agencies, academia, NGOs and industry to share technology and innovation. Networks should be developed within the country and with other countries, including through south-south cooperation.
c. Implement short-term-training measures to rapidly fill capacity gaps, while also establishing a long-term strategy for national capacity development by providing support to students.

5.2 Statistical design

Planning, definition and implementation of the scientific design can commence once the preparatory work and assessments are complete (the identified information needs, the set of variables to be observed derived from the expected products, and the available resources in terms of prior information, expertise and budget, which will define the framework within which detailed planning of the statistical design will take place).

Three major criteria guide the planning of the statistical design: (i) meeting the information and precision goals, (ii) staying within the allocated/available resources, and (iii) adhering to methodological and scientific soundness.

The last criterion constitutes the foundation of credibility and ensures that the NFMS results are defensible. This is important because NFMS results may come as an unexpected or unwelcome surprise to many observers. Methodological and scientific soundness is the only means to obtain objective, "reliable estimate" information on forests, and to defend the results. Methodological flaws and inconsistencies and even just lack of transparency or completeness in documenting the methods applied may put the credibility of the NFMS at risk. Therefore, defining a sound statistical inventory design that follows scientific principles and complies with state-of-the-art research is one of the most relevant – and most demanding – tasks in NFMS planning.

Definition of the statistical design is a complex process that consists of various components. In forest inventories, for example, the two most prominent data sources are sample-based field observations and remotely-sensed imagery. There are numerous options for their integration and combination. In the case of forest inventories, however, some series of variables may not be directly observable, either in the field or through the use of remote-sensing data, and models and/or auxiliary data will be needed to help "convert" directly observed variables into variables of interest. These models may be available from prior studies or will need to be developed as a part of the accompanying research for the forest monitoring system.

In planning for statistical design, the following principles need to be considered: *Principle 5: Research infrastructure and capacity building, Principle 9: Flexibility approach, Principle 11: Feasibility including cost-efficiency, Principle 13: Credibility through transparency* and *quality, and Principle 14: International collaboration.*

5.2.1 Integration of field and remote-sensing data

Sample-based field observations and remotely sensed data are commonly the most important data sources in forest monitoring. Both data sources have their specific characteristics in terms of the variables that can be directly observed, their "availability and accessibility", their cost and the expertise required, as well as their analysis and reporting options.

Field observations are the core of any forest assessment and relatively large sets of variables are recorded during national forest assessments, generating results on biomass, species composition, diameter distribution and regeneration, illegal logging and socio-economics – although remote sensing approaches are making rapid advances.

Remote sensing is useful during the sampling design phase (including pre-stratification and optimization of sampling and plot design) and in the estimation phase. It plays an indispensable role when spatially explicit analyses and reporting (maps) are required or when retrospective analyses are at stake (as is the case for assessment of historical deforestation trends in REDD programmes). Remote sensing may provide spatially continuous data on auxiliary variables (e.g. vegetation cover, NDVI). These auxiliary variables may contribute to improving the estimation of core variables (through techniques such as post-stratification or double sampling).

Figure 3 illustrates the major processing steps of data from both field and remote-sensing sources and their typical integration into NFMS.

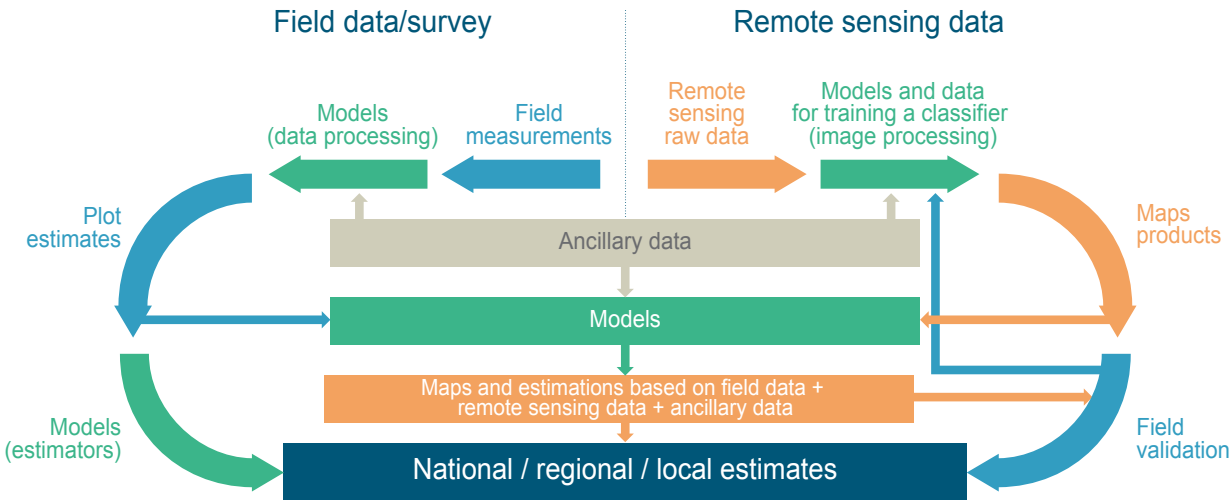

Figure 3: Major processing steps for data from field and remote-sensing sources and their typical integration into NFM

The integration of field observations and remote sensing shall include the following points:

a. Both field sampling and remote sensing should be strictly objective-driven. They should contribute to meeting the information needs and/or satisfying broader research goals.
b. Ideally, the same definitions should be used for variables drawn from field and remote-sensing observations. This requires attention, as it can prove challenging to apply exactly the same definition to both data sources for definitions such as "forest".
c. Statistical rigour and methodological strictness shall guide data acquisition from all data sources. A clear protocol therefore needs to be developed for both types of data acquisition and analysis.
d. When planning field data collection it is important to remember that field observations may be useful for the validation of remote-sensing image analysis.
e. To the extent possible, include geographical coordinates of the collected information, such as plot centres (or corners) and tree centres.
f. The semantic interoperability between descriptors (definitions and terminology) used to specify the ground and remote-sensing measurements should be well defined and understood, in order to avoid confusion over terminology and to guarantee that data can be jointly analysed in a straightforward manner.

Products based on remote-sensing data should always be calibrated and validated with field referenced data. This improves map accuracy and allows the production of continuous maps of target variables, for example, forest biomass maps.

5.2.2 Sampling design

Statistical sampling in the context of forest assessment refers to the strategy for selecting sample points within the target area, in accordance with the considerations in Section 5.1.1 (e.g. country area or the forest area of the country), and the manner in which the sample observations are carried out around these sample points along a defined approach. This is called the "plot design" (see Section 5.2.3).

Sampling design is the strategy by which these samples are selected. This refers mainly to the selection of spatial positions of sample plots. In the context of national forest monitoring it also refers to the temporal positions. National forest inventories cover large areas and frequently have a relatively large sample size. As such, it may take several years to complete the sampling before analysis can begin. An unambiguous reference point in time needs then to be defined. However, in many cases, results – even if only intermediate results – are demanded much earlier. One solution

Box 14: Periodic or panel approach

It is an important decision regarding sampling design whether every x years a complete inventory shall be carried out (periodic approach) or whether a so-called panel system is implemented where every year a set (panel) of samples is worked on (panel approach).

is to organize the sampling over several campaigns carried out annually or biannually, with each covering a certain percentage of the total sample (Box 14). This is called a panel-based approach because sample panels are observed every year. For example, if the inventory cycle is planned for 10 years, then one-tenth of the systematic grid may be observed every year. This would result in a fairly coarse grid, but after the first year an up-to-date estimate may be produced, albeit at relatively low precision.

Sampling is relevant in at least two important statistical contexts in forest monitoring. First, field observations are sample-based and serve to produce estimates for a number of forest inventory core variables. Because field observations are commonly a very time consuming and costly component of a forest inventory, it pays to put sufficient efforts into optimizing the sampling design, such that the defined precision goals can be reached with the least effort and cost. Second, samples of field observations are required in accuracy assessments of remote-sensing map products. In both cases, a methodologically sound analysis and interpretation of the results is possible only if the sampling studies rigorously follow the rules of statistical sampling.

This is probably the most relevant criterion in choosing a sampling design: that a methodologically sound analysis must be possible. This means that an estimator framework must be available (either through formulae or simulated estimates) that allows for statistically sound estimation. It is not a good idea to select the sampling positions in a non-statistical manner (i.e. arbitrarily or subjectively) because this excludes the possibility of performing methodologically sound estimations and may compromise the credibility of the NFMS altogether.

Almost all national forest inventories employ so-called design-based sampling, where the unbiased estimation depends exclusively on the statistically sound selection of the sample points – and not on population characteristics. A straightforward and methodologically correct selection procedure for the sample points is therefore imperative.

Box 15: Simple random and systematic sampling design

There are essentially two basic sampling strategies that are used as elements in all sampling designs: simple random sampling and systematic sampling.

Simple random sampling can be analysed in a straightforward manner and unbiased estimators are available for all statistics. It is frequently used in classrooms, because it is highly instructive and often required for inferential statistics (e.g. tests).

However, simple random sampling is highly inefficient for the practical application of forest inventories, which instead frequently make use of systematic sampling as a basic sampling strategy. There are many approaches to systematic sampling; in one of the most commonly used square grids are placed over the area of interest and predifined points that fall into the population of interest (e.g. forest land) are taken as sample points.

An issue in statistical estimation with systematic sampling is that there is very limited randomization. When using a regular square grid, for example, there is only one randomization stage to define the location and orientation of the grid. Consequently, there is no statistically unbiased estimator for error variance (and therefore precision), while there are unbiased estimators for the mean.

However, simple theoretical considerations and numerous simulation studies have shown that, when applied to forest inventory, systematic sampling is always more precise – in many cases much more precise – than simple random sampling with the same number of observation points. This has to do – in general terms – with the fact that a systematic sample evenly covers the whole population, capturing variability; and that there is always a defined distance between neighbouring sampling points, keeping autocorrelation between observations low.

Therefore, it is commonly accepted that precision estimates in systematic sampling are approximations only. In many cases, the variance estimators of simple random sampling are applied to systematic sampling, and it is understood that this will result in conservative estimates. This means that the true – but always unknown – error variance is lower (often much lower) than the estimation yielded by application of the simple random sampling estimator.

In statistical sampling, the strategy employed to select sample points is randomization. Other general and not well-defined concepts such as "objectivity", "fairness" or "representativeness" of selected sample locations are not acceptable.

Box 15 describes two common basic sampling designs for forest inventory: simple random sampling and systematic sampling. In practice, however, systematic sampling is commonly applied and often combined with sampling design options such as stratification, plot design options such as cluster plots or estimation design options such as the integration of auxiliary variables.

Once a sample position has been selected, for example, with grid coordinates in a defined system, this position is fixed and must not be modified. The sometimes-practised approach of plot-shifting, when a sample point position does not appear to be suitable, is by no means permitted. This also holds true for plots where no observations can be made (non-response). These non-response plots should not be replaced by new plots that have not been initially selected. Even if a sample point falls into an entirely open area within the forest, without trees, this point must be taken as sample point and recorded. Essentially, the open area around this particular sample point forms part of the defined population, as with any other tree-covered sample position. However, non-responses may occur (Box 16).

A key issue when defining the sampling design is to establish the appropriate sample size, that is, the number of sample points needed in a field to establish observation units (sample plots). Sample size is one of the main factors influencing precision of estimation: assuming all other conditions remain constant, a large sample size results in higher precision, but also in higher cost. The relationship between precision (in terms of simple standard error or width of the confidence interval) and cost is important: in simple random sampling (and similarly for other sampling designs) improving precision by factor f requires an increase in the sample size of factor f^2. For example, decreasing the precision of estimation from a 95% confidence interval of 20% to a 95% confidence interval of 5% (f=4), would require a 16-fold (f^2) sample size. This example shows that decisions regarding sample size and desired precision levels must always take cost considerations into account.

When determining sample size as a function of desired precision, it is important to focus on the most relevant variable. Basal area is frequently taken as the variable for sample size optimization, because it has shown to be well correlated with other important forest inventory variables and is relatively easily measured.

Sampling also has certain limitations. One such restriction concerns the estimation of rare events ("rare" meaning low frequency over either space or time). It is impossible to produce very precise estimations for rare elements from a national-level forest inventory sampling study, because the sample size would increase prohibitively. This means that if rare events (i.e. rare or endemic species in biodiversity studies or localized deforestation) are among the priority target objects identified in the information needs assessment, it will be necessary to devise additional studies specifically for their estimation, possibly in a research-oriented context, integrated with detailed remote-sensing studies.

Box 16: The non-response

Once selected, sample points need to be located in the field to establish sample plots for observation.

However, in some cases pre-selected sample points cannot be reached for security or safety reasons, or because the forest owner refuses to not grant access.

In these cases, observations will not be possible and these sample points are recorded as "non-responses". Non-response is a common feature in inventories. The term is drawn from interviews/surveys where certain interviewees refuse to answer questions.

Non-responses become a challenge when the percentage rises above a few percent. Sampling statistics offer some methodological approaches to deal with non-responses. However, nothing can replace a direct observation and it is important to keep the percentage of nonresponses as low as possible.

NFMS planning shall take into account the following points when considering sampling design:

a. Statistically defensible and well-documented approaches should be used that have generally accepted estimation procedures.
b. Refrain from inventing new selection mechanisms for which statistically sound estimation procedures are not available.
c. Desirable properties of the sampling design include the precision of the estimates, cost-effectiveness, simplicity both in terms of understanding and implementation, and adaptability for monitoring over time. Common adaptations include technological and methodological improvements and adjustments for changes in policies and emerging information needs.
d. Remote sensing may be used as a powerful tool to increase efficiency (e.g. stratification, double sampling, model based inference).
e. Devise and document clear instructions for field teams on how to locate the selected sample points. This also includes unambiguous definition of the spatial reference system in which the coordinates are given.
f. Give clear indications on how to deal with non-response cases when the pre-selected sample locations cannot be reached.
g. Consider building upon existing experiences of forest inventory sampling studies. Lessons learned from past efforts and implementation experiences are very helpful, in particular when these efforts are well documented. If possible, the inventory planners should try to contact those responsible for planning the design of these earlier inventories. Usually such experiences are highly instructive.
h. Keep in mind the permanent character of the sample. Sample plots should be revisited during the next inventory cycle to allow for precise change estimates. Sampling designs that restrict the future utility of the sample must be carefully thought through. For example, although stratification is a generally powerful and useful variance reduction tool, it is important to select stratification criteria that are stable over time. Otherwise, estimating changes will pose a challenge after 10 years or so, once the strata change. At the same time, it is important to consider all key variables when planning stratification, as stratification that may improve estimation of one key variable may prove ineffective

for another. Computation of the sample size for key variables should be based on precision requirements or the available budget. This is often an iterative process with precision requirements or budgets adjusted according to the information needs, national circumstances, and the technical, financial and human capacities.

i. Sampling design considerations are strongly linked to considerations of plot design in terms of precision and cost-effectiveness.

5.2.3 Plot design

While the sampling design determines how to select sample points, the "plot design" describes the activities to be undertaken at the sample point. It indicates how to include sample trees and other sample objects, and how to perform measurements and observations of the variables.

As with sampling design, there are many different plot design options. For a more comprehensive and detailed treatment of this subject, the reader is referred to forest inventory textbooks and the scientific literature. This guide presents and discusses only some basic points and criteria. In national forest inventories, it often takes considerable time and effort to reach the sample points. The goal is therefore to make optimal use of the presence of the field team at a particular sample point. This frequently leads to very complex plot designs that combine a number of basic elements such as nested fixed-area plots, relascope plots and linear observational units and others, with the aim of recording around 100 or more variables.

Sometimes individual plots or nested sub-plots are located only around the selected sample point. More often, however, a cluster of sub-plots is installed in a defined geometric pattern around the same point, especially in large area forest inventories. Common approaches include square clusters with four or eight equidistant sub-plots, cross-shaped clusters with four or five sub-plots, or L-shaped clusters (also called "half-squares") with an uneven number of subplots. This subdivision of the sample plot into several spatially disjoint sub-plots enables a higher degree of independent information to be collected per sub-plot. This will increase the overall level of precision compared to approaches with sub-plots joined together or located at very short distances. Numerous factors determine a cluster plot design, with research into ways to optimize the design playing an important role during the planning stage. Data from prior inventories where cluster plots were used may offer excellent opportunities to simulate different cluster designs and to learn about spatial autocorrelation in the forests to be inventoried. However, this option requires well-documented data sets.

Plot design options that can be combined at the same sample location, forming a set of sub-plots, include nested fixed-area plots in circular, rectangular or square shapes for trees of different dimensions (e.g. small regeneration, established regeneration, small trees, large trees); relascope plots for the estimation of basal areas; and large plots for the assessment of terrain conditions, habitats and indicators of biodiversity, transects for down woody material, and possibly also soil cores (see Box 17).

All sample plots used in forest inventory exhibit some form of spatial extension, except when simple points are used as a sampling unit. In this regard, all sample observations must relate to the horizontal plane and the population of interest. This means that if sample plots are located on sloped terrain (and many forest areas are indeed situated in hilly and mountainous areas), they need to be duly corrected for slopes. Sample plots (real or virtual) whose area

Box 17: Designing sampling and experimental plots

The overall guiding statistical principle when designing observation plots is to capture the maximum possible variability per plot. Conversely, when establishing experimental plots the goal is to make the plots as homogeneous as possible in order to reduce confusing results.

With observational studies such as inventories, however, maximum variability per plot results in higher overall precision of estimation.

From a purely statistical point of view – and given the omnipresent autocorrelation structure of forests – the aim is therefore to design inventory plots that are spatially "extended" rather than compact.

exceeds the population boundary will also need to be corrected. Ignoring these corrections will lead to errors that cannot be corrected later and will impair analysis and estimation.

Another important issue in defining plot designs for field sampling is the potential use of field plots as inputs in remote-sensing analyses. There is no clear and generally valid recommendation for the optimum design of field samples to allow combination with remote sensing, if such joint analysis is foreseen. Remote-sensing-derived observations may be used as auxiliary variables to improve forest inventory estimations. Remote-sensing analysis may also be used to produce regionalized maps of important forest inventory variables as well as for small-area estimation. In both cases, field and remote-sensing observations need to be co-registered, so that they can be jointly analysed. In such cases, it is crucial to determine the exact field position of the plot.

For the joint analysis of field and remotely-sensed data, fixed-area plots with a defined reference area on the ground are more suitable than plots with variable or virtual plot areas or line samples. As of yet, there is no clear evidence that sample plot shapes and sizes that directly mimic the instantaneous field of view of satellite sensors – that is, multiples of square pixel sizes – are superior in that regard to rectangular or circular plots. For example, laying out square fixed-area field plots of 30 m, 60 m or 90 m side length (that correspond to multiples of Landsat pixel sizes) in the forest is extremely tedious, and it is doubtful whether correspondence with the satellite sensor's pixel size justifies these additional efforts. Instead, it is recommended to guide field plot design along statistical criteria and criteria for operational feasibility in the field.

As with the definition of sampling design, planners should take care to ensure that sound estimation options exist for all selected plot design options. It is relatively quick and easy to devise a plot design that describes how to include specific trees and take certain measurements; it is another story to develop unbiased estimators for such plot designs. In particular, when sampling rare events, it is necessary to develop adaptive plot designs. Adaptive strategies require very clear, pre-defined rules – and they should only be used if estimators are available.

When defining the plot design, the following points shall be taken into account:

a. Employ plot design elements that allow all variables identified from the information needs assessment to be observed.
b. Various different plot design options can be combined to establish nested sub-plots.
c. Use only plot designs for which straightforward statistical analyses are possible and refrain from inventing new data collection approaches without developing suitable estimators.
d. Duly apply slope and boundary corrections.
e. Measurements per plot shall be operationally feasible in terms of time and equipment.
f. Field sample plots for national forest inventories are commonly established as permanent plots to be revisited after a set time period (e.g. 5 or 10 years). The planned plot design and measurement procedures should take this into account by, for example, recording accurate coordinates in a well-specified spatial reference system and landmarks.
g. Determine the optimal size of field teams and working time for performing measurements and observations per plot.
h. If possible, organize field plot size and workload to enable the field team to undertake the work in a single day, including travel time. If difficulties of access hinder this approach, the field teams may have to remain in the field, which will result in additional logistical and cost challenges.
i. Ensure that all stages of plot establishment, including measurements, can be documented transparently in the field guide.

5.2.4 Estimation design

In the context of sampling design and plot design, it is vital to select techniques that allow for straightforward statistical estimation. Such "estimation design" includes identifying and defining analysis algorithms and the estimators (formulae or simulated estimators) to be applied once the data are collected and quality checked. It is recommended to develop all details of the statistical estimation process early in the planning phase. This will help to prevent the use of sampling or plot design elements for which

Box 18: Estimation as a core element

It has been observed that significant effort is often devoted to specifying how many and which data should be collected (i.e. defining the sampling and plot design), while less effort is spent on planning data analysis during the early stages of the process (i.e. estimation design).

It is therefore strongly recommended to consider estimation as a core element of the NFMS from the outset.

statistical estimation is unclear or impossible. It will also help to identify potential gaps in the variable list. Due care and consideration at this stage will facilitate the implementation of data analyses and estimation once all data are present. A well-prepared, transparent and consistent estimation approach is a prerequisite for the credibility of the whole NFMS process (Box 18).

This step necessitates a very good command of sampling statistics in forest assessment and requires the services of experienced forest survey statisticians.

The following points shall be considered when defining the estimation design during the planning phase:

a. Ensure that all analysis stages and corresponding estimators are consistent with the definitions of sampling and plot design.
b. Prepare all analyses required to produce the expected outcomes according to the information needs assessment.
c. Thoroughly discuss the approach with the team of analysts and document it step by step, including the software implementation used. This step-by-step analysis may then be used as the starting point and basis for the description of results and methods in the reporting stage (see Section 5.4.5).
d. Consider the use of estimators that integrate easily with maps or remotely sensed data, so as to improve precision and provide spatially explicit information.

5.2.5 Model selection

Many variables of interest cannot be measured directly and, instead, must be modelled from others that can be observed more easily. Models therefore form an integral part of any NFMS. A typical example is individual tree biomass from

which stand and forest biomass are estimated. As Individual tree biomass cannot be measured unless the tree is cut and weighed, models must be used. While the models will never yield the true biomass of a particular tree, they provide the best possible approximation in the inventory context.

The most frequently used models predict volume from diameter at breast height (*dbh*) alone or from *dbh* and *total height* and possibly further variables (e.g. diameters at upper sections on the stem); and allometric biomass (and carbon) models that predict individual tree biomass (or carbon) from predictor variables such as *dbh, total height* and wood-specific gravity. In addition to these models, the most common for biomass estimation are based on biomass conversion and expansion factors that – depending on the definition – convert and expand, if necessary, the (above-ground) tree volume, itself estimated using a model from measured values, to the total (or above-ground) tree biomass. When using these models, care should be taken to exactly match the available proxy variables, the conversion and expansion factors (depending on whether these are available separately or as combined values), and the biomass that needs to be estimated.

Volume, biomass and carbon variables are of high interest in national forest monitoring. Accordingly, a large number of models exist to predict these variables (both tree and area-based). In the some cases, biomass models based on measurements from the inventory region may be available, which are designed specifically for the major tree species present. In many cases, however, models are absent for most species, particular in highly diverse tropical biomes. A number of general multi-species models have been developed for such situations. However, when using general global models or models from other regions, it is important to be aware that considerable uncertainties may be introduced.

Judging whether a model at hand is suitable and applicable to a particular situation is a methodologically challenging task: a quality assessment must be carried out for all models used in an inventory. Here, "quality" refers less to how well the particular model fits the sample data upon which it was built, and more to how well the model matches the specific population of interest.

When selecting suitable models, one shall consider the following:

a. Find out whether locally specific models had been developed. This information is frequently found in the grey literature.
b. If local models are not available, there are two options: (i) make use of global models, which may introduce considerable uncertainty, or (ii) develop specific models – a generic research task that can be quite laborious.
c. If possible, quality-check models for their suitability before applying them to a specific project.

5.2.6 Errors in forest inventories and quality assurance

Forest inventories are complex; they involve numerous methodological steps and experts and staff from different fields of expertise. Such a system is prone to errors and uncertainties. Box 19 briefly explains the meaning of "error" in the given context.

There are various sources of residual variability within forest inventory systems and a number of ways to incur real errors (as distinct from "real errors").

There are four major sources of errors in residual variability. These are described below along with actions to minimize error levels:

Measurement/observation error

- Measurement errors occur when measuring or observing a variable. Typical examples of measurement errors in forest inventory include repeated measurements of *dbh* by different staff leading to deviations in measurements or misidentification of tree species. When measurement errors should be explicitly taken into account, repeated measurements of the same objects need to be taken. If this is integrated into the standard inventory procedure, it needs to be clearly described in the field manual.
- The goal is to keep measurement errors low. This is achieved through good preparation by field teams, the use of well-calibrated measurement devices (to measure metric variables), complete lists of classes (for categorical variables) and identification

Box 19: Errors

In empirical statistical studies, the term "error" describes the residual variability, not mistakes or failures.

In this sense, errors are omnipresent and cannot be entirely avoided.

The goal of NFMS survey planners is to identify the sources of errors, to address them where possible, and to reduce them to the extent possible and economically feasible.

"Real errors" also occur in forest inventory studies, for example, as a result of incorrect usage of measurement devices or mistakes in transcribing down observations. There have even been cases where inventory teams faked the field forms instead of visiting the sample locations in the forest.

Causes of such "real errors" need to be addressed very seriously. This is principally an issue of training and ensuring that all staff are treated with due respect and understand that each of them has an important function to perform.

keys (e.g. for nominal variables such as tree species). Another equally important factor in maintaining high-quality standards – and one that is frequently ignored or underestimated – is the need to show appreciation for the hard work of field teams and keep them actively motivated.

- For the purpose of subsequent analyses and estimation, measurements are commonly taken as true, unless a specific assessment of measurement errors is integrated into the NFMS.

Model error

- Whenever models are used in forest inventories, they affect the residual variability. This stems from the fact that predictions from models do not reflect the true value of the observed tree, but rather a conditional mean value from a set of sampled trees.
- For example, when applying allometric biomass models, model errors in terms of the distribution of deviations between predicted and true values cannot be quantified in a forest inventory without time-consuming additional measurements.
- Model errors originating from the use of remote sensing also compound field data-associated model errors, and should be considered when reporting uncertainty.
- As mentioned in Box 15, errors associated with non-response exist in many NFIs, and are particularly important when the lack of response is not random. Imputation techniques to assign values from other measurements exist and may be applied, but need to be considered carefully, as they might artificially inflate precision in the final estimates.
- The values taken from models are frequently assumed to be true. However, when model errors are known, they should be taken into account in analyses and estimation.

Standard error

- Standard error is the residual variability caused by the use of a set of sample observations to calculate estimations, rather than observing everything, which would enable calculation of the true value (in the absence of other measurement errors). The estimations vary as a function of the sample elements selected in a particular sample. The standard error is a function of the sample size, plot design and the variability present in the population. As plot design and sampling design are defined to ensure the availability of statistical estimators, standard error can be estimated in a straightforward manner. This procedure is commonly included in all types of forest inventory. The standard error for all-important variables is in these cases calculated and reported together with the estimates (e.g. mean values).

Non-response error

- The presence of missing (or non-response) data is particularly likely in complex or multi-source inventories. Errors associated with missing data can contribute greatly to biases in predictions if these unavailable data are systematically distributed over a certain gradient. The uncertainty related to missing data is unquantifiable. However, it can be minimized through either further data cleansing, re-weighting of the data, or otherwise imputing values to those missing data from regression techniques linking the existing data to auxiliary information from the same inventory data or external sources, such as remote-sensing products (see Box 16).

When reporting only standard errors, it is implicitly assumed that no other error source has been quantified. However, because measurement

and model errors also exist, it can be safely assumed that the standard error is the lower bound of the total error.

Some simulation studies point to the fact that the standard error of estimation is – at least for core variables such as growing stock or basal area – by far the largest component in the residual variability. In other cases, measurement errors may be higher.

There are many possible causes of "true errors" (= failures), the most relevant of which are listed here:

- Poor design of field forms including missing or unclear explanations and instructions, and inappropriate structure and presentation of questions and tables, can cause errors.
- Poor field protocols can lead to illogical data or may not provide guidance on how to collect information associated with uncommon field conditions.
- Data entry errors may occur where required information is not entered or is transcribed incorrectly from paper forms into the computer. Modern field data loggers offer comfortable options to verify the input data entered directly in the field. To enable this, the range of realistic values needs to be identified for each variable; values outside that range are not permitted or need to be explicitly confirmed by the user. Outlier detection techniques constitute an independent core of statistical approaches used in the detection of many of these errors.
- Errors may be caused by misreading measurement devices.

These true errors can only be tackled by proper data collection protocols, good training, efficient supervision and good motivation of field teams (which includes fair payment and fair treatment of both men and women), as well as continual contact and communication both with and among field teams to enable the exchange of experiences.

It is recommended to start data processing (calculation) as soon as the first data are available, as these may reveal unexpected errors.

While errors cannot be eliminated altogether, the goal of NFMS assessment planners is to reduce them to the extent possible, both in economic and logistical terms, in this context a NFMS shall:

a. Start data processing (calculation) as soon as the first data are available, as these may reveal unexpected errors.
b. Include quality assurance/quality control (QA/QC) plans – another technical design component of national forest inventories. Quality assurance/quality control (QA/QC) is critical for any empirical study including a forest inventory.
c. Ensure that high-quality data are collected by providing clear and complete definitions and descriptions of the measurement procedures. Reducing measurement and observation errors is an important element of QA/QC.
d. Evaluate and document data quality.
e. Use findings from the evaluation to apply corrections, where and if at all possible.

5.2.7 Design of control measurements

Control measurements by supervision teams, sometimes referred to as "check cruising", constitute a key measure in the context of QA/QC. As a general guide – and as a general measure of QA/QC – about 10% of field plots should be quality checked by a supervision team. The regular field teams must be aware of this and must also understand the importance of high-quality measurements and the consequences of non-compliance. Accordingly, measurement tolerances and measurement quality objectives (MQO) need to be developed and documented. Tolerance is the range of acceptable values (e.g. $\pm$1 cm for *dbh*). The MQO refers to the percentage of time that the measurement must be within this tolerance interval (e.g. 95% of the time).

Measurements of plot size are possibly even more important than individual tree measurements. If the plot area is wrongly determined or the slope correction forgotten or badly done, this may have a significant impact on the extrapolation from plot values to per-hectare values. It is also very important to ensure that the plot is well documented and correctly positioned. If GPS measurements and the documentation of reference points/landmarks are of low quality or mistaken, this will compromise the chances of locating the plot again in the next inventory cycle.

The recommendation to verify about 10% of field samples constitutes the extent of standards on control measures in national forest inventories. There are no generally established standards on how to select supervision plots (Box 20), determine threshold values or define consequences in the case of non-performance of field teams. All these points need to be defined specifically in a protocol for supervision measurements for the particular inventory.

The following points shall be observed when designing the technical components of fieldwork supervision:

a. Control measurements are extremely important and function as standard elements of any forest inventory sampling process.
b. All field teams should be evaluated.
c. All sample points should have the same probability (i.e. larger than zero) of being checked, even if they are extremely difficult to reach.
d. Hot checks should be started early during field inventory implementation, in order to ensure that correctable errors are not committed over a longer measurement period.
e. The results of early hot checks may necessitate an intermediate training workshop or another platform for exchange of experiences between field teams.
f. Quality standards to be met need to be defined. There is no such thing as a general standard for measurement errors (admissible deviations) or observation errors (misclassifications). There are also no standard procedures for dealing with non-performance. Instead, this forms part of technical and operational planning and needs to be defined by NFMS planners in detail.

5.3 Operational design

The term "operational design" refers to all activities involved in setting up fieldwork and the information management system of a NFMS. It is indispensable for the successful implementation of the NFMS.

The elements of operational design relate to standard project planning, which requires skills in all issues related to project implementation including human resources, communication and logistics.

All operational planning activities serve to implement a cost-efficient system that maintains high data quality. Reducing errors is among the most relevant planning criteria. However, in the context of statistical design planning and quality assurance, sources of errors (both residual variability and crude errors) must be addressed. Any error in field observations propagates directly to the final results and affects data quality. Random errors increase residual variability and systematic errors introduce biases. Both are unwanted.

Reducing errors and maintaining high data quality standards are among the criteria for all planning steps in operational planning. For this reason, a NFMS shall:

a. Assemble a field guide that prioritizes high quality standards and the highest possible

Box 20: Some strategies for measurement supervision

Supervision may be implemented through different strategies. It is recommended to employ all of them. The extent to which the different strategies are followed depends largely on the particular circumstances:

- *Hot checks*: experts accompany field crews to the field and monitor, correct and discuss field team procedures that are either inefficient or may lead to errors. Such supervision resembles continuous training and quality improvement.
- *Cold checks*: the supervision teams go to the measured sample points with a copy of the field sheets. They repeat the measurement, either completely or using a specifically designed supervision measurement protocol. Comparison of the supervision measurements and the original field measurements then serves as the basis for the quality assessment (QA). The results will help to identify crews or individuals with quality issues that need to be addressed.
- *Blind checks*: expert or regular crews are sent to plots without the previous crew's data or knowledge and measure the plot as if it were a new plot. Producing regular QA assessment reports in this manner provides users with the information needed to assess the repeatability of measurements and plays an important role in ensuring transparency and accountability.

For cold and blind checks, software should exist to quickly compare results and provide a scoring system to see if the data meet MQOs.

level of consistency for data collection.

b. Develop an information management system to collect, store and clean up errors in the data based on the field protocols.
c. Establish a training programme that serves to "calibrate" the field teams according to the protocols stipulated in the field guide and to harmonize and standardize all observation procedures between field teams. It will also motivate teams to care for data quality even under difficult field conditions.
d. Introduce a supervision mechanism of independent control measurements to undertake quality checks for field data collection.

Operational design follows and relates mainly to the following principles: *Principle 5: Research infrastructure and capacity building,* and *Principle 11: Feasibility including cost-efficiency.*

5.3.1 Producing the field manual

The data collection process encompasses plot-based observations, interviews and house surveys, and is among the most expensive and time-consuming steps of the NFMS. Staff will be hired internally and/or externally to constitute the field teams responsible for the field observations. Their primary reference is a field manual, which includes the data collection protocols (field protocols). The protocols describe all aspects of the field measurements and observations in an unambiguous manner that can be used as a reference by all field teams. When used in association with efficient training sessions, the field manual is a means to standardize observations and achieve high data quality. It contributes to optimizing activities related to data collection and analysis, promoting the adoption of good routine practices for carrying out measurements, and efficiently managing time and staff. It also helps field staff to better understand their key role in ensuring high data quality.

Essential components of the field manual include definitions of terms and variables, measurement protocols, field forms, code lists, a list of necessary equipment and details of the allocation of tasks to team members.

The field manual should be amended or updated whenever measurement procedures need to be specified or more efficiently organized. Reasons for amendments include feedback from field teams, the emergence of new methods, and the need to clarify specific elements. However, caution must be exercised when definitions or procedures are changed. Alterations should not lead to inconsistencies within the data within a field season or from one inventory cycle to the next, as this would compromise the comparability of results for the current inventory and over time.

The field manual for a NFMS shall:

a. Be specifically tailored to the national circumstances and capacities, yet seek to be consistent with national and international definitions.
b. Provide both clear guidance and an operational and logical sequence of methodological steps for observation of the target variables, thus maximizing the efficiency of the activities and consistency of the data recorded between different field teams and over time. Normally, errors committed during the forest inventory field data collection phase should be kept to a minimum to avoid the need to revisit the same field locations.
c. Include an introductory chapter relating the background and justification for the particular inventory. This chapter should help the field teams (and other interested parties) to better understand the goals and concrete objectives of the study. It should also set out socio-economic information needs and related dimensions, such as how to effectively engage with both genders and specific groups.
d. Include a complete list of devices, equipment and materials that the field teams should carry with them to perform the measurements. This list serves as a checklist for the team leader before leaving for the forest. The list should also clearly mention the need to carry items such as spare batteries, first aid kits, and possibly a radio or satellite telephone. All teams should carry comparable equipment to ensure consistent information quality.
e. Include a clear description, including graphs, of the plot design elements and a step-by-step description of the measurements to be taken for each of the plot design elements.

The meaning and measurement procedure for each variable needs to be described.

f. Take into account various field situations in the definition of the variables and the measurement procedures. Try to avoid having field teams encounter situations in which the field manual does not give explicit guidance and teams have to make own individual decisions, as these may differ between field teams and lead to inconsistencies.

g. Clearly describe all classes and levels for all categorical and nominal variables, so that the field crew knows exactly which datum or code to enter for which variable. This relates, for example, to the measurement units and number of decimals for metric variables such as *dbh*, and a complete list of names/codes for nominal variables such as *tree species* (including the option "unknown" and a list of botanical family names for cases where identification down to the species level is not possible). Avoid pre-classifying variables, such as percentages, by recording the values directly and then grouping them into classes during analysis.

h. Provide guidance on: (i) how non-standard but foreseeable situations should be handled (e.g. describe what the crew should do if part of the sample plot is situated in the forest, while the other part is located in a river), and (ii) what the crew should do in situations where the field manual does not apply (e.g. describe what should be done if the sample plot is located in an area that has been recently disturbed).

i. Include an annex to the field manual containing instructions on the correct use of all measurement equipment and devices, including even the simplest devices such as callipers or tapes.

j. Thoroughly test the manual in the field under the full range of country conditions. This should be by the authors of the field manual and by other field teams.

k. The field manual should be printed in a form that can be easily used and accessed in the field. A small booklet, possibly laminated, has been shown to be very practical. The field manual may also be carried in electronic format.

l. Encourage field teams to comment on the field manual and add clarity by organizing feedback workshops and providing contact persons for comments and questions. In

the end, data quality depends on these individuals and their experiences in situ can provide valuable material for optimization of the field manual. Any changes should result in a new version of the manual, and versions should be tracked and archived over time.

5.3.2 Design of the information management system

A NFMS requires the creation of a well-structured and compatible information management system, where all data are stored, managed and maintained over the long term.

The data management information system needs to be well documented with metadata files describing variables, and with clearly identified categories or ranges of values for categorical and numerical variables. All these descriptions need to be compatible with the field manuals that describe the data.

To ensure effective data management, a NFMS shall:

a. Document the database and provide metadata on various aspects of the NFMS, such as model coefficients and references, sample design and plot configuration.
b. Establish and employ standards for data content, classifications and technologies used. Harmonization of variables may be required when different standards are applied to the same variable within the country.
c. Determine/design the data collection software and compatible hardware needed, especially if using portable data recorders are used.
d. When re-measuring plots, consider providing printed records of previous measurements for each plot.
e. Provide storage and back-up facilities for both raw field data and clean data, preferably on a central server.
f. Create a policy on data sharing with special attention to personally identifiable information and plot coordinates. Create an easy-to-access platform for sharing data for wider use.
g. Develop protocols and mechanisms for data sharing.
h. Ensure that personnel are not only able to complete tasks regarding data entry and analysis, but also able to update or modify databases when necessary. Training courses can help.
i. Document the estimation methods and models chosen with related statistical model formulas and the computer code used.
j. Establish protocols for geospatial data, including metadata, processing methods and accuracy assessments.

5.3.3 Building the teams

There are various tasks involved in implementing and running a NFMS; some are permanent tasks and some are temporary. All tasks require specific expertise and staff. As with all programmes, efficiency of procedures and quality of outcomes depend very much on skills, seriousness and motivation of all staff. Recruitment of the right people for the different tasks and generating an attractive working environment is therefore crucial for the success of the NFMS. "Attractive working environment" means, above all, absolute clarity about roles, tasks and responsibilities, as well as fair payment, fair working conditions and other benefits (e.g. free vaccination), and fair formal contractual conditions. The positions of all staff in the whole process (hierarchy and who reports to whom) and the related communication structure must be clear. It is important to retain skilled staff for institutional memory and to undertake auditing of field crews and other staff specialists, whether they are hired staff, contractors or partners.

Building teams to perform the different NFMS tasks shall include the following aspects:

a. If possible, recruit staff with prior experiences in forest inventory fieldwork, remote-sensing analysis, integration of information, GIS, etc.
b. Ensure that fieldworkers are able to perform physically demanding tasks.
c. Appoint team leaders that demonstrate good leadership abilities and who have prior technical experience.
d. Integrate young forest technicians or forest academics, as this contributes to long-term capacity development in the country.
e. Encourage women as well as men to join the teams and take practical measures to make sure this is possible for them. This is key to engaging effectively with local communities.

f. The composition of the field teams in terms of number of staff and hierarchical structure needs to be defined as a function of the set of tasks to be carried out. Commonly, it comprises a field team leader, one or two field inventory technicians with national or regional experience, and temporary helpers who may also be recruited locally so that they can make available their local knowledge to the field teams.
g. Create other teams for planning/design, remote sensing, information management and data analysis.
h. Establish terms of reference for each team member, based on the NFMS component in which they work. These should clearly indicate the roles and functions that will be assigned to him/her by the team leader.
i. Clarify quality standards and the joint responsibility of the entire team.
j. Distribution of labour in the field is important and should be based on the particular skills of the individual staff. All staff should be encouraged to make suggestions to improve procedures.
k. Keep the field staff motivated. Forest inventory fieldwork can be physically demanding and over time, quality may suffer. Starting with recruitment, each staff member should be clear about the importance of high quality measurements by each individual.
l. Organize the technical teams in an integrated manner. The staff should maintain a dialogue between those who collect and analyse the field information and those who develop spatial information.

5.3.4 Training

Specific and sufficient training prior to implementation of the inventory work is fundamental. Standardized training enables teams to apply procedures consistently. Well-organized training workshops not only provide the "technical background" for data quality and consistency, they also provide a "team-building experience" by bringing various teams together and generating a sort of corporate identity.

It is not uncommon for adjustments to protocols to be made as a result of observations and suggestions during training sessions. It is, therefore, important that the experts who defined the field procedures and developed the field manual participate in these sessions, as these provide an excellent chance to identify potential weaknesses prior to implementation.

A NFMS shall consider the following aspects for training purposes:

a. The training should be calibrated to national capacities and based on a stepwise approach.
b. All teams performing the same kind of work should receive the same training. Overview training can be implemented in larger groups. Practical training sessions on the use of electronic measurement devices or training in the field may require smaller groups.
c. Examples should be provided to illustrate how to address the wide range of situations encountered in the field.
d. Field safety merits special emphasis. It is important to consider which vaccinations might be required, perform a risks assessment for the fieldwork and share the results of the assessment during the training sessions.
e. Teams should be trained on new technologies and tools as they are adopted.
f. Teams should be trained to collect socio-economic as well as scientific data, including how to engage with women as well as men and with specific forest user groups, etc.
g. At the end of the training session, each team should perform one or two hands-on examples under the supervision of instructors.
h. The duration of the training will depend on the complexity of the subject and the prior experience of the teams. It should cover all relevant topics, including both general introductory information about the relevance of the NFMS and specific topics.
i. The training workshops should form part of an integrated, durable and effective country capacity-development strategy.
j. The training workshops can include an exam at the end where a formal certificate is issued.
k. Exchange of knowledge and experiences among field teams is crucial. It is important, therefore, to encourage direct contact between participants over time.
l. To formalize such exchanges, an intermediate "training workshop" can be held soon after


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field implementation. This will serve as a platform for the field teams to exchange experiences and address particular difficulties encountered during implementation.

m. The training sessions should take place shortly before the planned work is undertaken.

5.3.5 Fieldwork planning

"Fieldwork" refers here to the process of collecting biophysical and socio-economic data in the course of specific forest inventory work, whereas "fieldwork planning" refers to the development of the implementation plan for the field inventory. Fieldwork planning is done by defining and prioritizing all necessary activities and their sequence, so that the specific goals of each component of the NFMS can be achieved as efficiently as possible within the budget. This entails a planning process for the completion of the proposed activities, wherein the inputs, resources and responsibilities are identified and documented. This planning process defines the work plan for the technical teams and requires both planning skills and forest inventory technical skills.

For the fieldwork planning the NFMS shall take in consideration the following aspects:

a. The NFMS fieldwork plan should clarify the goals and guiding principles (in particular, regarding data quality), define general and specific activities, specify the resources available, allocate the responsibilities of teams and staff members, and schedule their activities.

b. The operational plan defines the workload (the sample points to be measured) for each field team. Detailed planning is then the task of the field team leaders.

c. It is important to ensure the compatibility of the operational planning with the objectives and expected results of the NFMS, in the medium and long term.

d. Monitoring and analysis of resources should be performed to maintain cost-efficiency and ensure the planning remains within budget.

e. The operational plan needs to provide for all logistical issues including transport, measuring equipment and devices (including spares), emergency plans in the event of field accidents, and communication between field teams and between NFMS headquarters and field teams.

f. The operational planning should involve the field team, to the extent possible and practicable.

g. Operational planning encompasses planning for the supervision of fieldwork. This involves the constitution of supervision teams, the selection of sample points to be supervised, and the definition of a supervision measurement protocol, quality standards for a core set of variables and consequences when these standards are not met by field teams.
h. A continuous improvement process should be developed based on input from the field, office staff and stakeholders. This includes the fieldwork plan itself.
i. If available, auxiliary spatial data should be evaluated to determine whether the sample location does not constitute forest and whether it needs to be assessed using available information sources. It is also important to assess whether plots are accessible on the ground, such as restricted areas and geographical barriers. Spatial data can be used to help determine how best to access the location of samples to be visited.

5.3.6 Fieldwork implementation

Fieldwork takes place on the ground and involves plotbased observations related to forest structure and composition and other relevant characteristics, and may also include interviews with forest users and forest owners. The main purpose is to collect original data on the status of the forest ecosystem and the forest resource at a given place and time, both in terms of qualitative and quantitative variables. Fieldwork also plays an important role in establishing relationships between remote sensing and ground data.

The technical part of fieldwork is based on the field manual, while organizational and logistical issues are rooted in the operational planning.

The NFMS shall take the following aspects related to fieldwork implementation into account:

a. Fieldwork implementation refers to the concrete scheduling of fieldwork according to road and weather conditions, accessibility, fitness of the field teams and other practical criteria.
b. Field teams organize their fieldwork independently in accordance with the assignment of tasks formulated in the operational planning. However, coordination is maintained with NMFS headquarters to guarantee compatibility with NMFS goals and overall procedures.
c. The function and calibration of measurement devices must be checked regularly.
d. NFMS headquarters will be consulted in the event of doubts regarding any of the operational steps, so as to ensure consistency across the overall system.
e. Fieldwork procedures can be optimized gradually during the course of fieldwork, depending on the experience and skills of the team members and internal communication.
f. The main technical guiding principle in fieldwork implementation is to strictly follow the field protocol and maintain high data quality standards. The main organizational guiding principle is to ensure security in the field and avoid accidents.
g. Team dynamics also play a crucial role in forest inventory fieldwork. It is vital, therefore, that field team leaders maintain the motivation of all team members, by showing appreciation for their hard work and continually emphasizing the relevance of the contributions to the entire NFMS.

5.3.7 Supervision of fieldwork

Supervision of fieldwork in this context refers to "control measurements" or "check cruising", which are necessary to ensure data quality. Technical aspects of planning for supervision measurements and details about error sources are presented in previous sections and Box 19. There are many sources of errors and over time data quality may suffer. Independent supervision can serve to motivate field teams to maintain high quality standards, but also make clear that non-compliance and errors may have consequences. Supervision may be considered a continuation of training.

For the operational planning of supervision measurements, the following points shall be observed:

a. Supervisors must be forest inventory experts who are absolutely familiar with the field protocols and experienced in forest inventory fieldwork.
b. Independence between supervisors and regular inventory teams must be guaranteed

to the extent possible to avoid conflicts of interest.

c. A supervisor should accompany each crew (hot checks) early in the field season to avoid misunderstandings and errors in early stages. This should also be done with new crews added during the field season.
d. Supervision teams should revisit a specified percentage of each crew's plots with the crew data in hand, so as to identify error sources and the magnitude of errors in the data collected (cold checks).
e. Cold-check data need to be analysed rapidly and feedback given to the field teams. There may be cases of non-performance where a field team's contract needs to be terminated immediately. There may also be cases where field teams come up with excellent suggestions to improve the implementation of field procedures, in which case the field manuals should be revised accordingly.
f. Blind checks are conducted by revisiting a representative sample of all plots *without* the crew data in hand to ascertain whether the data are repeatable (for quality assurance). Blind checks can be performed by either supervision teams or regular crews.

5.3.8 Auxiliary data collection and supervision

Auxiliary attributes can be collected using existing maps and through interpretation of imagery. A guide should be written to describe the protocols for collecting each of these attributes. While collecting such information, maps and imagery can be used to help identify plots that cannot be accessed from the ground and those that can be "observed" exclusively from maps and imagery, such as plots falling on barren land. Maps and imagery can then be used to help navigate to the remaining plots. These activities are typically conducted prior to field activities and can therefore be referred to as pre-field data collection.

In a NFMS, the auxiliary data guide shall:

a. Identify relevant data sources (maps, satellite and other imagery) that provide the attributes identified in the information needs assessment. Other attributes for inclusion relate to the accessibility of the plots. Check the quality and other characteristics of the sources, such as map accuracy, resolution, scale, timeframe and cost.
b. Establish the protocols for acquiring, processing, extracting and assigning the information spatially, including to individual plots, as appropriate. Protocols must also include metadata standards.

5.4 Data management, data analyses, documentation and reporting

Once the field data are collected, they must be safely and permanently stored to ensure they are easily accessible for reference and further analyses. Permanence of data availability is one of the constituent elements of an efficient NFMS. Quality control before analyses should be carried out systematically based on the field data collection methodology. Statistical data analyses should be designed to respond to specific questions, as formulated in the information needs assessment, and to produce additional results which may stem from research questions. The results then need to be converted into reports for broader audiences (Figure 4).

Reports to address information needs (see Section 4.2) should target key stakeholders both in terms of content and format. Such external reporting should be performed in tandem with internal reporting. The latter consists of a thorough analysis of experiences during the cycle of national forest inventory implementation, both in terms of technical implementation and compliance with stakeholder expectations. These "lessons learned" will enable the NFMS to gradually improve performance at all planning and implementation levels.

This phase requires a variety of expertise including in data management and storage, informatics, and statistical data analyses, as well as in communication and public relations. Additionally, the final stages consisting of critical reflection and impact analysis (lessons learned) require expertise in the whole process of national forest monitoring.

The "Data management, data analyses and reporting" element relates mainly to *Principle 5:*

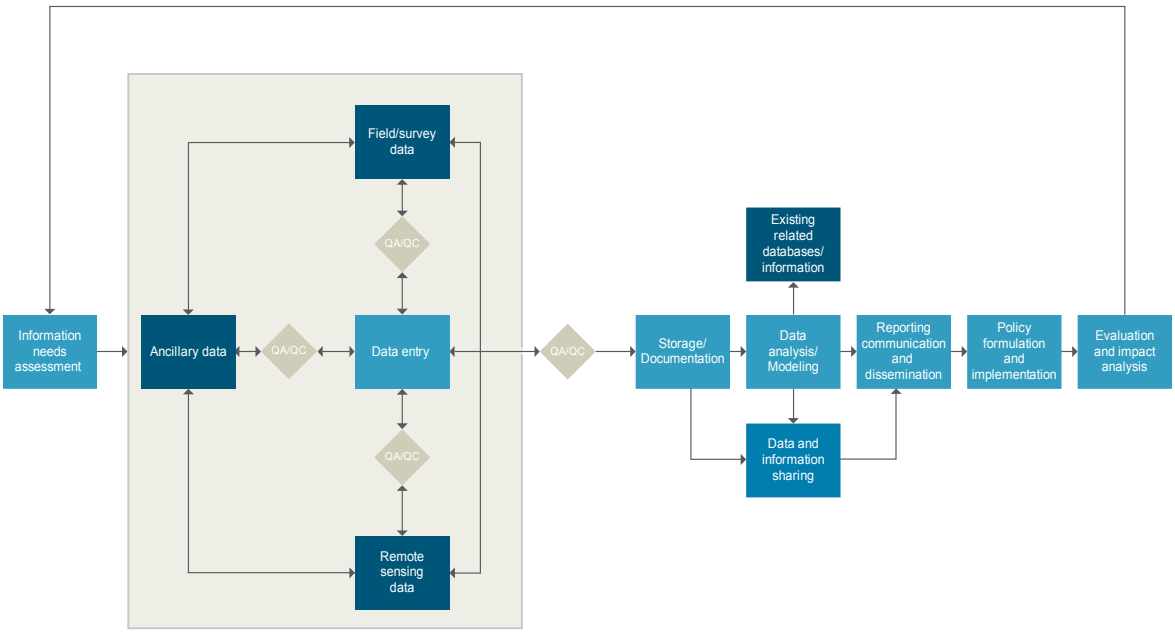

Figure 4: Data management framework of a NFMS

Research infrastructure and capacity building, Principle 1: A well-defined data and information sharing policy, and Principle 13: Credibility through transparency and quality. It should be noted that the way in which institutionalization has been organized will define the implementation of data management, data analyses and reporting.

5.4.1 Data entry and management

When making plans for data entry and management it is crucial to think ahead. Data must be stored in a way that allows it to be retrieved using future technologies, including hardware and software. This includes thinking about future software upgrades and formats for data exports.

Data management starts with recorded data. The underlying technology of this data will depend on the type of data collected (e.g. remote sensing, manual analogical data entry and digital data logging). Both raw field data and "clean" data need to be permanently stored and backed up. Ideally, a single, current copy of the data will be stored on a central server (with an exact copy on another server), rather than as multiple versions on multiple individual PCs. This approach facilitates data integrity, currency and sharing.

A NFMS requires an efficient data management system that encompasses data entry, quality control, and archival and long-term accessibility of both collected data and associated metadata.

Once the information management system has been designed and installed, the entire system has to be documented. The documentation should include a description of the data (including its source), the database information system (including the database structure) and the metadata (i.e. a set of terms and definitions that describes the data in terms of availability, location and accessibility), if possible, in internationally standard format in accordance with data collection protocols.

To ensure effective data management, a NFMS shall:

a. Implement a detailed database structure and management protocol (including hardware and software requirements).
b. Use data formats that will be in use for the foreseeable future and that permit interoperability, rather than developing and/or using custom-built or obscure formats.
c. If part of the data is exported for analysis using different software, the integrity of the source database must be ensured.

d. Data stored in the system should include metadata comprising the description of the various datasets (e.g. age of creation, location, data owner, access rights, etc.). The format of metadata should follow international standards to the extent possible.

5.4.2 Data quality control

Before any analysis is performed it is important to enact a final data quality check and subsequent cleaning and correction. A limited set of errors can be detected and corrected at this stage; however, cross-checks with the situation in the field are usually not possible and the errors detected refer mainly to internal inconsistencies and values beyond realistic ranges. Correction will be easy in some cases (e.g. if the decimal point was obviously shifted for a measurement value) and impossible in others (e.g. if a species was incorrectly identified or the plot location incorrectly determined).

The following quality-check actions shall be performed when managing the database:

a. Re-check the data in the office. Edit checks that should have been conducted in the field should be applied to the raw data, especially if a field data recorder was not used. Raw data should be archived and any changes should be applied to a copy. Further checks can be performed using graphical and summary statistics to identify outliers for further examination. Finally, appropriate methods for filling in missing data or correcting obviously incorrect data should be devised and implemented, wherever possible.
b. So-called outliers need to be very carefully checked before eliminating them. They may represent extreme cases, and not errors.
c. Provide protocols for data cleaning and apply them to the database in order to ensure consistency of the data.
d. When making changes, record why and how the changes were made (e.g. if an outlier is excluded, explain why).

5.4.3 Data analyses

Data analysis is the stage at which questions posed in the information needs assessment are addressed. However, other analysis needs might arise over time in which case both the questions and assumptions applied during the analyses must be precisely identified and stated. The analyses should be based on sound science and a good knowledge of the database, how the data was collected, and what variables and models can be used for meaningful analyses.

Before the results of the analyses are published, a quality control of the estimates should be conducted (e.g. by performing an analysis using alternative methods, tools and consistency checks).

In forest assessments all results of sample-based national forest inventories are generally estimates (e.g. estimated mean values such as biomass per hectare), which are always accompanied by a measure of uncertainty (e.g. error variances and confidence interval). As mentioned in Section 5.1.4, such a confidence interval does not accurately quantify all sources of uncertainty in a national forest inventory. However, it does yield a very useful order of magnitude.

With regard to data analyses and estimation, a NFMS shall:

a. Ensure that data analyses and estimation are led or supervised by experienced staff who are familiar with the numerous analysis pitfalls in forest monitoring data analyses.
b. Strictly consider all statistical elements of sampling design and plot design and follow generally accepted estimation procedures for point estimation and interval estimation: once the design elements are defined and fixed, there are commonly only a few choices for the estimation design. It should be noted that for the most commonly used sampling design (i.e. systematic sampling), unbiased variance estimators for design-based sampling do not exist (see Box 15). However, commonly used estimators of simple random sampling tend to be conservative (i.e. overestimate the variance).
c. Ideally, clarify and test the analysis estimation design with test data in order to ensure that the statistical estimation design for the analysis is correct.
d. Use auxiliary data from other data sources to improve the estimates, when appropriate.
e. As estimates of change have different

Box 21: Meaningful estimates

When producing sample-based estimates for defined spatial units or reporting, it is important to note that there are downward limits to the size of these reference units.

Meaningful estimates can only be produced when a sufficiently large number of sample plots falls into the corresponding region.

For very small areas, estimates may be meaningless due to inferior precision of estimation.

measures of uncertainty than estimates of single measurements, calculate these accordingly, so as to check whether the calculated change is significant or not.

f. Provide estimates for the whole country (national level estimates) and for sub-national units of reference, as defined in the planning phase.

g. Use existing software tested for use on forest inventory estimation (standard, free and/or open source) for all analyses. Efforts to develop new software may introduce significant programming errors.

h. Check and correct inconsistencies and errors in the data that can only be detected during analyses.

5.4.4 Documentation

To ensure that the entire NFMS is transparent, managed over a long period of time, reviewed, used appropriately and credible, all relevant elements of the system must be described in detail and this description archived. The documentation should include all relevant information on the design and implementation of the monitoring process (e.g. manuals, protocols, description of methodologies including assumptions, tools, maps and imagery, raw and processed data, software, staffing, costs, etc.). The documentation should be well structured and accessible at any time, so as to ensure that all elements of the system can be reproduced and used in the future. These may include the expected data for analysis, any assumptions taken into consideration, gaps that were/are present and suggestions on how to improve the analysis.

The protocols used for data analysis should also be documented to enable others to perform the same analysis (see Section 5.4.3).

5.4.5 Reporting

Reporting serves to communicate the results and findings of the NFMS to stakeholders (whether national or international), including federal and local governments. Reporting should be accurate, complete, consistent, comparable with similar estimates produced by other NFMS, transparent and accessible. Both the content and the format of the output of the analyses should match related information needs by stakeholders.

The aim of reporting is to: (i) deliver scientifically sound results derived from the NFMS to the stakeholders that need them; (ii) publish the methodology, including assumptions and gaps; and (iii) report on information concerning the accuracy and statistical tests of the results.

The ultimate value of the NFMS depends on how well it delivers the required forest-related information in a specific and timely manner. In order to be credible, it is essential to also assess and report the uncertainties of the results.

Compliance with the above requirements is particularly relevant for international processes that require forest information. Countries participating in these processes have to deliver credible information on a regular basis about the status of their forest resources and their efforts to monitor them, often with very specific reporting guidelines.

The NFMS may also make available raw data to the public or to selected stakeholders. This may increase both transparency and data use. Care should be taken in such cases to provide information on the methodology used for the data collection and to provide guidance on interpreting the data, so as to avoid misinterpretation.

With regard to reporting, a NFMS shall take in consideration the following points:

a. The method of reporting should be tailored to specifically meet the information expectations of stakeholders, both in quantitative and qualitative terms. This includes the coverage of variables, the format of results, and an assessment of what the derived numbers may

mean. Some reports are directed towards policy processes and decision-makers. Specific sections (e.g. on socio-economic aspects) could usefully summarize issues such as forest use (equitable or not). However, research institutions may have a strong interest in NFMS data and might benefit from an online database with built-in standard reporting functions.

b. NFMS reports should be stand-alone documents. They should enable readers to understand the results without reference to other sources.
c. The reports should explain the strategic goals and the political mandate and scientific justification of the NFMS. They should also present the numerical results for all spatial units (national and sub-national levels) and provide a complete description of the methodology.
d. As both results and methods are commonly very comprehensive and may lead to lengthy reports, it may be a good idea to publish the results and methods in separate volumes, depending on stakeholder needs. Options include a report containing a summary or summary for policy-makers, another consisting of an executive summary followed by all detailed information, and a further volume containing the relevant methodological information with reference to other publications for further details. In general, the complete and detailed reports are directed at inventory experts, whereas the summary reports are directed at inventory laypersons including policy and decision-makers and the general public.
e. The report should provide answers to the questions for which the NFMS was designed. If shortcomings are found during the reporting process, a means should be established to use that feedback to refine and improve NFMS procedures. If a question cannot be answered, details should be given as to why and conclusions drawn as to whether the question is still relevant and/or what needs to be done to provide an answer .
f. Reporting should include information on how the QA/QC was performed and the results.

5.4.6 Communication and dissemination

As noted earlier, communication and dissemination of information is a critical part of the initial information needs assessment and stakeholder engagement. It is also of primary importance in the reporting process following the data analyses. The NFMS is not a process in itself; it defines its relevance and justification from the fact that it responds to information needs. Therefore, the overall value of the NFMS is limited if the data collected are not converted into useful information for forest resource stakeholders. In addition, this useful information has to be delivered to stakeholders in a form they can readily understand and use.

Goal-oriented and well-packaged (i.e. useful) reporting and dissemination also increase interest in and utilization of NFMS data by generating new ideas through examples and informed interpretation (Box 22).

Communication and dissemination of NFMS reporting shall:

a. Identify the means by which the results will be communicated to all stakeholders including those previously identified and possibly others. This can include dissemination via all types of media, including TV and radio, various Internet tools, scientific papers, newspaper articles, educational materials, etc.
b. Once NFMS results become readily available, raise awareness of and encourage their dissemination to all stakeholders.
c. Obtain feedback from users, including international bodies that require reporting, concerning the utility of the reports with respect to content, format of the data and presentation of information.
d. View reporting activities as a way to promote networking, further stakeholder participation and engagement, and encourage collaborative efforts across different public and private sectors.
e. Be mindful of opportunities to engage the national and international scientific communities with technical studies that explore the data, and which can be presented in peer-reviewed scientific literature. Results and experiences from one NFMS cycle

Box 22: Communication and dissemination

The planning and implementation of communication and dissemination generally receive less attention during the NFMS process than the more technical stages. This is probably a consequence of the fact that inventory statisticians and resource analysts are not necessarily well-trained and well-experienced communicators.

Sufficient resources should be allocated to the communication and dissemination of results. A good option might be to contract a professionally trained communication expert to accompany the entire NFMS process and undertake active "promotion" of the NFMS process and results.

Much can also be learned from the experiences of other countries, both in terms of success stories and failures.

constitute an excellent starting point for research to optimize the next cycle.

f. Use the process of analysis, reporting, systematic information dissemination and responding to subsequent information demands (including demands for raw data), as an opportunity to build national capacity and reach new audiences for the NFMS, and to further build institutional, social and political support.

g. Highlight the value of the NFMS both domestically and internationally through the high quality of all products, thereby strengthening institutional and political support for the programme.

5.4.7 Dialogue on the NFMS and its results

Reporting, communication and dissemination should also be used to conduct dialogue on all aspects of national forest monitoring with any interested party, while ensuring an impartial and transparent assessment of the entire system.

NFMS data and information provide scientifically sound results to better inform stakeholders and reduce speculation. Forest-related discourse both within governments and between governments and NGOs or the general public is frequently quite controversial, partly due to the lack of proper information. Scientifically sound information may help to raise such discourse to a better-informed level. One important means of ensuring scientifically sound results is to systematically validate the entire system, including its design and all its results.

To ensure that the NFMS is continuously updated, the NFM process should systematically include dialogue on issues related to the design, operation and expected results of NFMS cycles by organizing workshops and discussions. These workshops may be general in character or focus on the needs of (and possible inputs from) stakeholders, for example, conservation NGOs, forest research institutes, the wood-processing industry, rural development NGOs and so on.

In order to foster dialogue on the NFMS programme and results, a NFMS shall:

a. Identify a suitable format of dialogue for each particular stakeholder group.

b. Involve representatives of stakeholder groups in the preparation of these discussions.

c. Ensure that NFMS experts are also invited to participate in the discussions, so that they can have an opportunity to inform participants about the methodological details and results, and clearly explain the strategic background of the NFMS.

d. If needed, ensure the high-level involvement of both the NFMS management and planning team, and all other stakeholders.

e. The discussions should be moderated to manage expectations and ensure that all voices are heard.

f. To ensure the discussions are effective, prepare examples of evidence-based results, including information on uncertainties, that support or contradict arguments used in forest-related discourses prior to the availability new inventory results. Such examples include information on deforestation rates, the development of species composition and other biodiversity-related topics, illegal logging, invasive species, the potential effect of incentives for sustainable forest management, etc.

g. Adapt and strengthen the programme and its associated institutions by documenting and learning from the stakeholder feedback and discussions, so as to better focus future efforts, within feasible limits, with regard to information needs, technical aspects, the inclusion of neighbouring sectors, and internal and general capacity development.

5.4.8 Evaluation and impact analysis

A systematic evaluation should be performed in the final phase of each cycle of the NFMS, in order to learn lessons from the process and further improve the system. The reporting, communication and dissemination steps offer plenty of opportunities for critical reflection and may generate considerable feedback.

All actors involved in planning, implementing and analysing the inventory, as well as all stakeholders, may have potentially relevant observations. The evaluation and impact analysis aims to gather as much of this feedback as possible. Because a NFMS is a complex system and each national forest inventory cycle is a technically complex project involving many staff with different responsibilities, many recommendations will be put forward, some of which will be contradictory.

In addition to the evaluation, a systematic impact assessment should be carried out to ascertain the actual impact of the NFMS. This assessment may be needed to justify the funding required for the NFMS. The main questions to ask in the assessment are: Who is using the NFMS? What results are they using, how often, and for what purposes? The answers to these questions provide extremely important information for NFMS managers regarding both the results. However, very few NFMS have implemented a systematic impact assessment. As a result, no standard exists for such assessments and it can be very difficult to track the use and impact of NFMS results. The internal evaluation and impact assessment are commonly the task of high-level NFMS managers. However, it is important to ensure that an independent, external evaluation is also conducted from time to time. All evaluations shall include the following steps:

a. Compare the actual results with the information needs, as expressed prior to the inventories. Some information may be missing and some data may not match stakeholder demands.
b. Analyse whether the precision requirements were met for key variables and identify potential solutions in cases where they were not met.
c. Evaluate the data collection procedures. This should be undertaken in communication with the various data collection teams with particular attention paid to the experiences and reports of the supervision teams.
d. Perform a cost analysis and identify the most costly components that may need adjustment.
e. As part of the impact assessment, find out whether policy and management decision-makers received the results in forms that meet their needs.
f. Install a mechanism and tools to track who is using particular results, for what end and how often.
g. Identify how NFMS information is used in legislation, policies and measures.

Concluding observations

Establishing and running a NFMS is a complex task for governments that serves to better inform forest-related decisions and, thus, supports the sustainable development of forests at the national level. It requires a long-term vision and interdisciplinary collaboration, and is both a demanding and exciting endeavour.

Typically, a NFMS will be implemented using a step-by-step approach with continuous enhancements made in line with feedback from user experience and the available resources.

The authors hope that these guidelines support this process by placing NFMS in the broader context of national forest-related decision processes and by addressing a number of relevant strategic, operational and technical points.

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