Food and Agriculture
Organization of the
United Nations

Knowledge reference for national forest assessments

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Food and Agriculture Organization of the United Nations
Rome, 2015

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ISBN 978-92-5-308832-4

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Foreword

The Food and Agriculture Organization of the United Nations (FAO) has been monitoring global forest resources for many decades, through its Forest Resources Assessment (FRA) programme and by providing direct country support to establish national forest monitoring systems.

In an era where interest in the world's forests has grown to unprecedented heights, FAO's commitment remains strong. In recent years FAO Forestry Department has made significant progress in its ability to directly support countries in their efforts to assess the extent, quality and importance of their forestry resources. Country support is delivered through a variety of means which together comprise a tool-kit available to facilitate countries' capacity development. This knowledge reference (KR) for national forest assessments is a further tool to be used for country support with the objective of giving countries autonomous and continuous capacity to monitor their own forests.

The production of this publication was made possible thanks to the collaboration of the Swedish University of Agricultural Sciences (SLU) and the contribution of experts in the field of forest inventory who shared their knowledge on a voluntary basis. In this updated and improved version of the KR, all phases of forest inventory workflow, from planning to field work and reporting, are covered. The content is available both in the form of the present publication and via a web portal, and all material is available in English, Spanish and French.

The KR is a collection of scientific articles prepared specifically to cover the wide range of activities involved in setting up and carrying out an assessment of forest resources at the national level. As such, it provides an invaluable resource for various stakeholders, not only within government, but also for the private sector, civil society and academia relating to the forestry sector. The KR is used in FAO's country support to develop national capacities in forest assessment and monitoring, and can be used free of charge as teaching material.

A series of self-study exercises are included in the web portal and are specifically targeted at students and younger generations of foresters. While FAO will remain strong in its commitment to monitoring forest resources, it is confident that this publication will help to improve knowledge and broaden the discussion on the importance of national forest inventories.

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Acknowledgements

The production of this publication was made possible thanks to the collaboration of the Swedish University of Agricultural Sciences (SLU) and support from the Government of Sweden. Sincere gratitude goes to the experts who shared their knowledge on a voluntary basis: Krister Par Andersson, Netra Bhandari; Raymond Czaplewski; Lutz Fehrmann; Klaus Janz; Christoph Kleinn; Barbara Koch; Steen Magnussen; Ronald McRoberts; Ylva Melin; Tuula Packalen; Reidar Persson; David Reed; Mats Sandewall; Göran Ståhl; Alan J.Thomson; Erkki Tomppo. Coordination and support by: Ulf Söderberg (SLU) and Marco Piazza, Dan Altrell, David Morales (FAO). Cover design: Maria Guardia (FAO). Content design and layout: Roberto Cenciarelli (FAO)

National forest assessments and policy influence

Reidar Persson and Klaus Janz

THIS CHAPTER DISCUSSES THE FOLLOWING POINTS:

- The current status of knowledge on forests worldwide.
- Inventories have often given correct answers to wrong questions.
- Across all countries there is a need to continuously re-evaluate the importance of key forest issues.
- It is important to base data collection around specific questions that require an answer.
- At national level, information needs revolve around policy formulation.

Abstract

This chapter presents the background and objectives of national forest assessments (NFAs), treating them as important tools to influence or monitor policy processes. It also discusses how national policies affect the NFA process.

The chapter also describes the past and present role of NFAs and potential future trends regarding NFA utilization. The synergistic relationships between ecological, economic and social functions of forests are considered, for example investment opportunities in concerned countries and the importance of cost benefit analyses for NFAs.

Lastly, the following questions are explored:

- Why have some aspects of the situation not changed over the years? For example, why is important information still missing and why is existing information not used?
- Are politicians interested in solid data and expert estimations?
- Is more information needed and, if so, what type of information?
- What issues should NFAs avoid?
- How will the increasing emphasis on the United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (UN-REDD) influence NFAs?

Forestry is not about trees, it is about people. And it is about trees only insofar as trees can serve the needs of people. (Jack Westoby)

1. Introduction

The collection, analysis and use of information at national and provincial level are strategic in nature. The information is used primarily in the development, implementation and monitoring of national forest policies and sector strategies. At present, however, many countries exhibit serious shortcomings in

the supply and use of information required for forestry policy-making. The principal weakness is often a failure to link the supply of information (the producer) to demand (the user). In many cases, collected data remain little used, while policies, strategies and plans are developed in the absence of solid information. In many developing countries, information is still gathered along traditional lines and is often inadequate, largely because donor-driven inventories neglect to undertake analyses of actual needs.

Demand for forest information is also changing. Historically, forest inventories have focused on variables of major interest for commercial timber exploitation, such as growing stock and increment. However, the last 20 years have seen increased interest across most countries in other forest values, such as biodiversity conservation, water quantity and quality, benefits and impacts of forest management, erosion or flood protection, carbon sequestration, recreation, and aesthetic, spiritual and wilderness values. Rapid urbanization in many parts of the world is also altering the relationship between society and forests, with new urban populations demanding different types of goods and services. Native forests are becoming less important for wood production and many countries are aiming to produce the bulk of their required wood within relatively small areas of intensively managed plantations. As a consequence, broader "natural resource management" issues, such as biodiversity conservation, water and carbon sequestration, are nowadays often more important to policy-makers than wood supply information.

Policy-makers also need a broad range of data for forest policy and management decisions. This requires assessment of a variety of areas, including: the social and economic dependence of communities on forests, the commercial and subsistence uses of timber and non-timber forest products, forest ecosystems important for conservation planning (including factors such as floristics, structure, age classes and disturbance history), recreation, heritage and other cultural values placed on forests in addition to potential wood supply. These assessments also require new tools that allow integration and analysis of data from different disciplines and sources.

This chapter argues *inter alia* that the gap between supply and demand of information cannot be remedied by improving the supply side alone (e.g. by introducing or improving national forest inventories); it is also the result of shortcomings on the demand side. As such, it is important to improve policy processes, including administrative environments that affect the production, flow and handling of information. Involving producers and users of data in this process is crucial.

This chapter also examines key questions relating to inventories: Why are inventories needed (including a focus on problem formulation)? What kind of information is needed? How can the links between information provision and policy-making be improved?

Interest in forest inventories has increased significantly in recent years, due in part to the establishment of REDD (Reduced emissions from deforestation and degradation) process agreements. Schemes now exist to strengthen capacity to carry out forest inventories in developing countries, based on new and foreseen national and global requirements for the future.

2. Why is knowledge of forest resources still poor?

Shortcomings in forestry-related statistics seem to have a range of explanations, but are seldom due to lack of techniques. Rather, the interest in using newly developed techniques carries a risk that forest inventories may become technique-driven instead of demand-driven, and focus on using the latest techniques instead of answering key questions.

Most of the shortcomings seem to be related to poor links between supply and demand of information. Some common problems in this

respect are:

- Mechanisms to formulate policy-relevant questions are lacking.
- The information presented is supply-driven. Inventories are undertaken based on procedures without proper analysis of the questions that need answering. As a result they tend to provide answers to irrelevant questions. Failure to identify actual needs is one of the main reasons why the information obtained is not fully used.
- Inventories are carried out under pressure from donors. In such cases they tend to be one-time undertakings and as such do not provide often-needed information on changes. In addition, few attempts are made to update the results.
- Inventories are sometimes undertaken on the basis of spurious or exaggerated claims that they are a necessary preliminary step to bringing forests under management.
- In some cases, information is kept secret or in closed government files.

Another category of problems relates to poor appreciation of the importance of information and inadequate allocation of resources for this purpose:

- Inventories are one-time undertakings that soon become outdated.
- There is a shortage of qualified personnel (lack of "capacity").
- Available qualified personnel are not given appropriate positions.
- It is difficult and expensive to collect information about forest use.

Finally, a number of problems relate to a lack of national commitment. The degree of commitment is influenced by many factors. One important consideration is the belief that knowledge is power. In many countries authorities may not want the true situation to be known as they may have vested interests, things to conceal, or may want to make claims unsupported by statistics. For example:

- Some countries with high deforestation rates may not want to publish the real figures to avoid criticism.
- Conversely, other countries may want to show the highest possible deforestation rates, in order to obtain increased support for forestry.
- Countries may not always want to publish plantation results because of failures that some officials may prefer to conceal.
- Significant levels of illegal felling may take place with the connivance of the forest authorities, who consequently may have limited interest in ascertaining the actual rate of use of forests.

In some cases, poor statistics are the outcome of suppression of information on the part of interested and powerful parties. In most countries, there is therefore a need to analyse the interests of different groups in relation to improving or suppressing statistics. Sometimes forces working against improvement may be so strong that any attempt to upgrade the statistical base will fail.

Alternatively, many forests have not been surveyed because they have limited commercial production potential or because the cost of extensive assessment is not justified by the extent of commercial resources. However, such forests are often important in terms of other social values, as described above. The declining contribution of native forests to timber production is also causing a reduction in the financial resources allocated to surveys of the extent and condition of these forests, despite their importance for other values. Emphasizing the economic value of forest products such as water, biodiversity or carbon sequestration, so as to justify investment in inventory, assessment and monitoring, can be a challenge for some forest managers.

3. Why is information needed?

The need for national-level information is driven mainly by the development of forest sector policies and strategies, their application

and the monitoring of their effects. If these needs are met, other needs may also be covered, for example:

- Fulfilling international commitments, for example, to the United Nations Framework Convention on Climate Change (UNFCCC) and the Convention on Biological Diversity (CBD).
- Responding to concerns expressed nationally and internationally for improved forest management and protection of forests.
- Providing information to market actors and other stakeholders, for example, to underpin forest certification or other processes aimed at demonstrating the quality of forest management in a country.

3.1 The policy process

The question of "why" is therefore linked to the role of information in the policy process. The political process is emphasized here for the reason that national-level information becomes meaningful only if a functioning policy process exists in the country. Theoretically, the policy process should precede information acquisition, whereas in practice the two are often developed simultaneously. The policy process should include a number of steps, as follows:

- Public debate ("political" or "scientific").
- Identifying problems and potentials.
- Designing options for (political) action.
- Analysing the consequences of such action (see p. 6).
- Decision-making (which option to choose).
- Implementation (see p.9).
- Monitoring (see p. 9).

This political process allows new objectives (the "national will") and new policies (the way to reach these objectives) to be formed. A crucial element is information about the supply and demand of forest products and services. Various studies are required, for example, to investigate the current situation and the need to adjust objectives, and to analyse the consequences of alternative policies.

As a rule, stakeholders should be involved throughout the process and great emphasis should be placed on consensus building, as stronger consensus leads to easier implementation. Governments change frequently but forestry is a long-term undertaking. As such, it is desirable that no drastic changes in policy occur after each election or change of government.

Feedback information is needed throughout all steps of the process. The general public as well as other stakeholders can only participate meaningfully if accurate information exists. The following list proposes issues for consensus building in a prescribed sequence:

- Basic facts about forest resources and their utilization;
- The nature of the main political problems;
- The options available to solve the problems;
- The consequences of different political programmes; and
- Decisions on which political action to take.

In this sequence of steps, consensus building becomes progressively more difficult, and the information required becomes increasingly complex. For example, analysing the consequences of alternative actions demands high-quality information and the ability to interpret it.

In practice, full consensus is hardly ever reached. In cases of disagreement, consensus should at least be sought over the nature of the disputed issues. Disagreement is often the result of varying perceptions with different participants viewing the same information in alternate ways depending on their own experience or situation.

It is important to emphasize that national policies and programmes for the forest sector must be integrated into national objectives and policies. If sector policies consider only sector objectives the result may be conflicting

programmes between different sectors. Even if policies are well integrated conflicts can occur, but such conflicts can be brought into the open and discussed. Conflicts about objectives are difficult to avoid.

In general, national objectives cover components such as employment, price stability, economic growth, balance of payments and income distribution. Statements of these objectives, in turn, lead to the establishment of national policies in the fields of environment and forestry. Forest policy should aim to fulfil the goals of society (and not just goals relating to forestry).

The notion of the political process as a starting point, responsible for identifying and specifying information needs, may seem too theoretical. In fact, both the political process and a system of forest information gathering are usually in place; what is needed is to link them together and make them work in a cycle. This can be done in different ways. In the Swedish example, such a link has been established through an Analysis Unit based at the Forest Agency (see section 6 of this chapter and section 2.4 of Chapter 2).

Sometimes the political process goes astray and opinions are created based on poor information. If this occurs, changing political opinion may prove difficult or impossible, even with accurate information. It is important therefore to have accurate information to hand at the start of the process. Transparency is also crucial in the political process so that those involved in information gathering can judge what information will be needed.

BOX 1

The political process - a national example

Once a forestry-related problem or issue (often a conflict) is identified and the government considers that political action is required, it appoints a commission of inquiry composed of parliamentarians representing the major political factions and advisers and experts representing government agencies, organizations and NGOs (stakeholders) who may be affected by the decisions taken. The commission undertakes a public investigation into the specified issue, following directives given by the government. It is given resources to commission ad hoc studies, appoint additional ad hoc experts and seek the opinion of stakeholders as needed. Its report is made public and actively circulated to stakeholders for their review. The report with the reviewers' comments becomes the basis for a government proposal to Parliament. Parliamentary decisions then provide a framework (e.g. a new law) within which designated authorities will supply the details (e.g. rules and regulations) required for its implementation. An informal process involves stakeholders, chiefly forest owners, in negotiations about the practicalities. This process is important for acceptance and smooth implementation, and facilitates the correction of any policy elements found to be inappropriate.

Source: Ekelund & Dahlin 1997

4. What information is needed?

4.1 General overview

As a matter of principle, data collection should be demand driven. The set of information to be gathered and analysed should be defined by need, rather than by ease of measurement with available techniques. Demand could be the result of an in-country analysis of national priorities, but could also evolve from agreements and negotiations between countries on international requirements. In reality, good practice requires that the development of NFAs and the collection of statistics be iterative processes. Sometimes the NFA will respond to a known demand, sometimes it will anticipate demand.

A practical way to approach the question of what information to collect is to identify what data are needed to analyse the consequences of political action (see below). This kind of analysis is highly demanding in terms of information. Data that satisfy these needs will likely satisfy most other needs.

One type of information that can be difficult to assess in this context is information on changes. This is crucial both for monitoring the results of new policies and strategies and the implementation of programmes.

It will also become apparent that some of the relevant questions cut across sectors and are not always considered part of forest administrations. Information acquisition for forestry planning involves far more than forest inventory. Some examples include:

- Information on the use of forest-derived goods and services
- Trade with such goods and services
- Contribution of such goods and services to the economy of rural households
- Employment statistics
- Stakeholder behaviours and expected reactions to policy instruments
- Greenhouse gas emissions and removals by forests and forestry.

Obviously, much of the information needed in the policy-making context is difficult to assess. In view of this, not all information needs will be met immediately. It is more realistic to assume a step-by-step improvement process. To begin with, it may be more important to formulate questions than to answer them. The needs for information will also vary from country to country and from case to case and should be considered with care.

Finally, a number of international processes have developed criteria and indicators of sustainable forest management for different forest types. In some cases, such as the Montreal and Helsinki Processes, these have settled on relatively detailed sets of indicators. Countries involved can choose those relevant to their circumstances and report them at a national level and in some cases at sub-national levels. In the process developed for tropical forest countries by the ITTO, the approach has been to develop a methodology to allow interest groups nationally or in a local area to determine those indicators of forest management most important to them. Indeed, international agreements tend to become increasingly influential on forest data requirements and also require countries to work actively to harmonize estimates, so as to ensure comparability across countries.

4.2 Analyses of consequences of optional policies or actions

Analyses of consequences are a key part of the political process. They consider action programmes that have been designed as different options, and simulate or predict what will happen if a given programme is implemented. The analysis of consequences as outlined here is often complex and very demanding in terms of basic data and techniques.

Scenario-modelling techniques are increasingly used for this type of analysis.

This section discusses a few complementary aspects of scenarios. For a more detailed discussion of this subject, see Chapter 11.

The political process begins with the identification of a problem. In the case of forestry, this could be deforestation, the poor condition of young forests, conflicting claims on land in certain landscape types or the loss of sources of non-timber forest products, among others. To address the problem a number of potential solutions are proposed (e.g. different programmes to promote the establishment of young forests of better quality). These may include legislation, research, special monitoring inventories, information campaigns and financial incentives. The consequences of each option (including inaction) then need to be estimated.

At this point it is important to mention the concept of production and consumption studies, developed by Nilsson (1978). These have provided key conceptual inputs into "analyses of consequences". A number of aspects can be emphasized:

- Studies in connection with forest policy development often focus on potential cut, allowable cut or similar quantifications of the supply side. In the policy context such studies become meaningful only if related (in comparable terms) to the demand side (e.g. fellings, removals or consumption). This also applies to non-wood goods and services.
- Realistic scenarios of future developments are possible only if current land use is known and well quantified. In addition, readers will understand forecast changes only insofar as they relate to a known starting situation.
- "Current land use" here includes knowledge of competing claims on land. In relation to forests this includes wood as well as non-wood goods and services.

4.3 Types of information commonly needed

This section presents a commentary on the information components needed in many planning and policy-making situations encountered in the context of forestry. Such a list will always be incomplete and should therefore be viewed as an initial checklist.

Land use

Conflict often arises over different land uses. It is important, therefore, to collect information about current land usage. Land can sometimes be used for wood and agricultural production at the same time.

Forest use

Most forestry practices aim to produce goods and services that people need. It is important to have information on quantities, patterns and trends in the production and consumption of forest products and their associated trade. At present, figures concerning, for example, exploitation may be only guesstimates, reflecting the formal level of allowable cut but bearing little relation to reality. It is also important to possess information about non-wood commodities and services derived from forests.

The present state of the forests

This is basic information collected in most traditional inventories. A characteristic of key importance is the capacity of forests to fulfil their functions. Normally, information needs concern areas, topography, ownership, accessibility, volumes and growth. More recently, information has been collected on forest types and ecosystem descriptions for conservation planning, including age information for "old growth" or primary forests.

Change

Policy-making usually requires information on changes over time, rather than mere status information. Only repeated or "continuous" inventories can provide such information of good quality. Comparability and accuracy are of critical importance in such inventories. It must be understood that continuous inventories imply secured, long-term funding and a stable organization. Most countries that

maintain continuous inventories have taken decades to build up the organization in charge.

Plantations

In many countries, especially in tropical/sub-tropical regions, plantations are established for specific purposes and are often intensively managed for fast growth and high yield (usually exotics). In the future, most wood is expected to come from plantations. More recently, forest land in many countries (e.g China, Viet Nam) has been distributed over a large scale to smallholder farmers and private entities with multiple objectives. In spite of this, information about plantations is frequently inadequate. The information needs for plantations are typically concerned with purpose, planted area by year, ownership and tenure arrangements, whether on previous forest or non-forest land, site class, species, survival, age, density, health and felling records.

Trees outside of forests

Trees outside of forests are an important forest resource. In a number of countries and regions (e.g. Bangladesh, Java, India, Pakistan) studies have shown that the majority of forest products originate from this resource (FAO/RWEDP, 1997). In spite of this, failure to collect information about trees outside of forests is a major flaw in many inventories.

The role of forests for local communities

In most developing countries rural people have traditionally depended on forests to a certain extent. "Industrial forestry" has evolved more recently, but there is a growing policy trend to let rural people benefit from nearby forest and tree resources (e.g. community forestry and farm-based forestry). This development brings a wide array of new information needs. In many countries, the knowledge and understanding of socio-economic issues in relation to forest use is insufficient among governments or forest management authorities. As such, the development of policies to strengthen the beneficial role of forests for rural communities and enable these communities to participate in sustainable forest management can prove challenging.

Other issues

A variety of traditional types of forest information have been mentioned above. There is, however, an increasing need for other types of information, for example, on biological diversity, availability, ownership including tenure, naturalness, protection status, forest health, forest fires, non-wood forest products, environmental benefits (e.g. hydrological effects), criteria and indicators for sustainable forest management. Appropriate inventory methods are not in place for some of these information types.

Carbon

The increased attention granted to carbon and hydrological services has provided opportunities to obtain payment for environmental services. In recent years, carbon sequestration has been presented on several occasions as the most important forest product. In the future this might cause significant changes to forestry and forest inventories.

4.4 Considerations before data collection

Assuming that the information needs are known, the primary consideration will be to ascertain what information is already available. Organizing this existing information may be a tedious process, but can save money and time. As a minimum, this task requires good archiving and retrieval systems.

A second consideration is the degree of accuracy needed for the intended purpose. A key question is what will be the consequence of an error of a certain size?

A third consideration is the amount of work possible with the available resources. If a new national or province-level inventory is deemed necessary, the relevance of the following characteristics to the policy issues can be considered:

- One-time versus continuous inventories;
- Local inventories versus large-scale, sampling-based inventories;
- Field observations versus remote sensing; and
- Inventories of forest resources versus information gathering on economic, social and administrative topics.

5. What follows decision-making?

5.1 Implementation

Governments and parliaments take decisions about new policies and strategies for forestry. The process that follows may take different shapes, depending on the circumstances. The following steps usually form part of the process:

- Legislation. Usually a new policy necessitates passing new laws. These laws need to be accompanied by regulations that specify the exact implications in quantitative and measurable terms.
- Revision of organizational and administrative structures. A new policy may require the adjustment of existing structures or the creation of new ones, for example, in order to prepare the ground for substantially increased extension services.
- Financial arrangements. A new forest policy may have far-reaching consequences for funding, subsidies, fees and taxation, which in turn may imply a need for further legislation and new budget arrangements.
- Getting the message out. Conveying the necessary messages to all concerned may require a substantial information campaign.

Many examples can be found in which good forest policies and strategies were developed, but little happened on the ground. In any case, implementation takes time and nothing will happen unless action is firm and well planned.

5.2 Monitoring

Once new policies and strategies have been implemented their impact must be monitored. Are the policies successful? What problems have been encountered? How have the forests developed? In most cases the actual developments will differ from the expected outcomes to a greater or lesser degree.

Substantial monitoring information can be collected by an NFA. However, it must be complemented in most cases by studies on specific aspects, such as the success of plantations, biological diversity, zoning for recreation and influence on local people.

Results from monitoring (and independent) studies are likely to lead to a public, scientific and political debate. In due time this will lead to requests for changes in the policy or part of the policy. The whole process will then commence a new cycle (or continue the previous one).

6. Linking information collection and forest policy

The planning and policy-making processes in the field of forestry often suffer from a lack of timely, accurate and relevant information. Among the many reasons the following could be highlighted:

- Much information may be present but fails to answer the key questions.
- Information exists but is scattered and spread across many institutions.
- Collected information has been lost or become inaccessible due to lack of good archiving systems.
- Planners and policy-makers have encountered difficulties in tracking and interpreting available information.

These issues raise the following questions: How can data collection focus on policy-relevant questions? How can existing information be organized to ensure its availability whenever and wherever it is needed? How can raw data be made available

to planners and policy-makers in a form that they can understand and use?

Based on the Swedish experience, an analysis unit may sometimes be an appropriate solution. This unit undertakes a set of tasks that link together supply and demand for information (or information gathering and policy-making). The tasks can be collected under one administrative unit or spread over several units that work together. The analysis unit would remain in close touch with policy-makers, so that it can aid in identifying key questions that need answers. It would also stay in constant communication with the data collection process, so that it can retrieve and organize existing information, identify gaps and collate relevant material for use in policy and decision-making. It would have the capability to identify sources of information, understand source information and prepare analyses. The presence of the Analysis Unit would facilitate dialogue between users and producers of information, making information gathering more demand-driven. By assisting policy and decision-makers on request with tailor-made information and studies, the unit would also acquire knowledge of the problems and needs of the user community. In addition, by interacting with data-collecting organizations it could feed back to them its knowledge of current and emerging information needs. It can also advise on needs for new research. The main tasks of an Analysis Unit are as follows:

- To undertake work to identify "topical" forestry issues;
- To create and maintain an overview of forestry-related information, which may be scattered in many places (e.g. information on the supply and demand of forest products and services, or on employment in forestry);
- To undertake ad hoc studies to support the formulation and implementation of forest policy, in particular analyses of the consequences of political action;
- To specify information needs that are not being met, based on contacts with users;
- To supply users with tailor-made information based on contacts with data producers – in particular, information compiled from different sources and presented in a consistent form;
- To promote and ensure comparability between information originating from different sources;
- To compile and disseminate standard information relating to the forest sector, for example, in statistical yearbooks;
- To take responsibility for the international exchange of information; and
- To analyse the consequences of various policies and actions.

The Swedish experience shows that long-term political commitment is necessary to make such a unit work well and that it takes decades to build up the necessary expertise. Good contacts with research are also needed. The creation of an analysis unit is often a process of adapting existing organizational structures. In some cases, the ideal method is to concentrate existing scattered activities in one place. The best approach may be to assign the described tasks to an identified group that is sufficiently large to build up an institutional memory. The importance of institutional memory cannot be sufficiently stressed. This remark applies to forest inventory work as well as to data analysis. In administrative environments with frequent changes of personnel it is very difficult to build capacity and progressively accumulate the knowledge that is needed.

An analysis unit also ought to be as independent as possible. Examples exist of units established in universities or government agencies. In many developing countries the university option may be a good solution, although it will require specific funding commitment and support on the part of the government as universities rarely have the resources to collect and store data, although other types of capacity are often available. However, the unit will require close contact with the forest administration to function, and this may not always be possible if a university

location is adopted.

However, the process described above differs significantly from common practice and experience. More or less sophisticated national forest inventories are often undertaken, but their usefulness is unclear. In a typical example, the original reason for undertaking the inventory may have been a forest policy problem such as deforestation and degradation. Combating this problem is a complex matter that affects many sectors of the economy and involves changing the living conditions and behaviour of many people. There is a general notion that more information is needed. In this situation it is only too tempting to request a forest inventory without detailing the precise questions the inventory is supposed to answer. There is then a great risk of the inventory being planned as a one-shot operation that will produce information of little use to the political process. It may give an impression of activity, and may be attractive to donors, but it has little chance of producing the knowledge base that is needed to develop and apply well-targeted policies.

In principle, an analysis unit (regardless of where it is located and how it is organized) is necessary for successful policy-making. It is not enough, though. Commitment to improve policies and make the necessary changes is also necessary. Moreover, the administration in general must also be competent and the administrative set-up suitable. (For more information on how to establish an analysis unit within an NFA organization, see section 2.4 in the chapter on *Organization and implementation*, p. 17.)

7. Emerging requirements

This chapter argues that a national analysis unit is needed to identify the key forestry questions and the information needed to answer them. The key questions will vary between countries and so will the information. Minor adjustments can of course be needed to meet some of the questions raised by e.g. The Food and Agriculture Organization of the United Nations' s Global forest assessment (FAO's FRA).

Recent years have seen a rise in the importance of carbon sequestration as one of the main forestry products. This could mean a drastic change for forest inventories. The United Nations Framework Convention on Climate Change (UNFCC) will identify the key questions relating to forests and may select the methods used to obtain the necessary information. The requirements of REDD and UNFCC may become so dominant that national needs may be overshadowed.

The new requirements will place more emphasis on continuous inventories and environmental monitoring and change information will become of increasing importance. New techniques may be developed that aim primarily at collecting information about carbon. However, there will almost always be a requirement for broader knowledge of forests than carbon stocks.

The development of REDD will not mean that the importance of national NFAs and analysis units will decrease, rather their importance will increase. Overly strong emphasis on the needs of REDD may leave many information gaps for traditional forestry. Furthermore, REDD may not generate equal attention and concern in all countries. If REDD is developing as optimists believe, this chapter will possibly have to be reformulated completely. As it stands, national needs must still be considered to be of primary concern for NFAs.

8. Conclusions

- Forest sector policies must be seen as an integrated part of overall national policies. Forest policies cannot be developed in isolation. There is a need for cross-sector cooperation.
- When dealing with information gathering, questions of a policy nature should be identified as a first step.

The collection of information (e.g. a national forest inventory) should follow thereafter.

- In most countries there is a need to analyse the interests of different stakeholders with regard to improved statistics on forestry.
- Countries should recognize the importance to policy-making and planning of information about the use of forests, change, plantations, trees outside of forests, non-wood forest products and the role of forests for local communities.
- Countries will need to establish an analysis unit in order to identify information needs and make effective use of forest information in policy-making. This unit should work to actively identify "hot" forestry issues, participate in the collection of statistics and analyse the consequences of different policy measures. It should work in close cooperation with both the policy-making authorities and organizations that collect information. A key task should be to identify needs for different types of information. The unit ought to be as independent as possible.
- Analyses and collection of statistics must be seen in the context of the political process and be designed to inform forest managers of the consequences of their actions. Forest inventories undertaken in isolation are of little value.
- The political process must prioritize consensus. This is a precondition for acceptance and smooth implementation. Planning cannot just aim at finding the technically best solution.
- Any forestry strategy must include an implementation strategy. Preparation of such a strategy requires significant work (and therefore often fails).
- Implementation of forest policies must be followed by adequate monitoring.
- The needs of REDD may imply an increased interest in forest inventories. If these needs become too dominant the value of forest inventories for other uses may be damaged.

Self-study exercises

- Discuss the interest of different stakeholders in learning more about forests. Do some stakeholders seem not to want better information?
- Which are the five most important forest policy issues that need to be discussed?
- Which ten types of information are needed in the first hand?
- How can forest policy formulation and information collection best be linked in your country?

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Organization and implementation

Göran Ståhl, Ylva Melin and Mats Sandewall

THIS CHAPTER DISCUSSES THE FOLLOWING POINTS:

- Organization and implementation are key issues for a successful NFA.
- Units for data acquisition, analysis and technical support are core components of NFA organization.
- The NFA is implemented through a logical sequence of activities.

Abstract

The success of a national forest assessment depends on many factors, such as an adequate selection of variables for assessment and a cost-efficient design. However, the organization and implementation of the NFA also require careful consideration. There are many available options for organization, but close collaboration with end users of the information and national knowledge centres such as universities is generally favoured. Depending on the available resources, the NFA may be organized either as a single integrated entity or as a larger entity split into different units. In the latter case, different options are available and one suggestion is presented in this chapter.

During implementation, the focus should be on ensuring a high-quality final output. There is a need for precise assessment procedures, continuous training of field staff, verification of assessments, and adequate resources and time to compile and disseminate the results based on the data acquired. This implementation process focuses mainly on NFAs based on field sampling. The need for capacity-building relating to the likely implementation of REDD, which is closely linked to NFAs, is also discussed.

1. Introduction

NFAs provide data for policy-related analyses of sustainable forestry and land use within a country. NFAs also generate data for reporting in accordance with international agreements and conventions, such as FAO's Forest Resource Assessments and the United Nations Framework Convention on Climate Change. In addition, NFAs often provide valuable data for research on issues relating to sustainable forestry.

The success of an NFA in a country depends on many factors. Naturally, an important basic requirement is that national stakeholders perceive a need for data about forests and other resources in order to analyse

different options regarding adequate land use or preservation of nature (Janz and Persson, 2002). Other crucial factors include how the NFA organization itself is set up and how it implements the assessment. For example, it is important to establish links between the NFA organization and end users of the information during the planning stage. It is also crucial to develop and maintain the correct mix of competences for NFA implementation.

The objective of this chapter is to describe and discuss the different available options for organizing an NFA, and to highlight key issues relating to implementation activities. Since the literature within this subject field is relatively sparse, the text draws on the personal experiences of the authors and discussions with colleagues in other countries.

2. NFA organization

There is no simple and clear-cut answer to the question of how an NFA should be organized. The point of departure, however, is that an NFA should be operational over a longer period of time, thus there is a need to establish a permanent organization. In the event that the NFA is carried out over a shorter period, consultants may be hired to conduct the assessment. Although this is not considered as an option here, the role of consultants may be important during the establishment of the NFA and other phases of organizational development.

The following sections discuss the role of an NFA and examine the trade-offs between inventory complexity and organizational requirements, before considering key issues and components of the NFA organization.

No specific references to NFA organization appear to be available in the literature. However, there is a vast general literature on organization and management, including the work of Dawson (1996) and Morgan (1997).

2.1 The role of the NFA

The suitable organizational structure of an NFA must be discussed in relation to the tasks of the NFA. These tasks may vary considerably. Considering the objectives of the NFA in relation to the degree of geographical and topical resolution in data and analyses, a number of broad cases can be identified. The objectives of the NFA may be:

- National-level analyses of sustainable forestry
- National-level analyses of sustainable land use
- National and subnational-level analyses of sustainable forestry
- National and subnational-level analyses of sustainable land use
- National, subnational and local-level analyses of sustainable forestry
- National, subnational and local-level analyses of sustainable land use.

In most cases the NFA prioritizes the first four objectives, although some assessments also seek to provide local-level data suitable as a basis for planning of forestry operations, forest conservation or land management relating to REDD (see Angelsen, 2009). Here, the role of the NFA is considered to be that of provision of national and subnational data valid for larger areas. Acquisition of local-level data is considered the task of other governmental bodies, forest owners or contractors. Thus, the scope of analyses based on NFA data is limited to the strategic level with acquisition of tactical and operational-level data (e.g. Thuresson, 1995) left to other organizations. Analyses based on NFA data typically include:

i. **Assessment of the current state.** This includes areas of different land-use categories and available forest resources (e.g. total biomass or volume available within a certain region of a country).
ii. **Assessment of trends.** Analyses that estimate changes between current and past conditions are becoming increasingly important (e.g. in the

context of REDD) where countries need to show that greenhouse gas emissions from forests have reduced.

iii. **Indirect inferences of cause-effect relationships.** For policy purposes, in many cases it is of interest to know the response of forest owners and other stakeholders to changes in legislation or institutional arrangements. For example, it may be of interest to study the extent of a certain kind of land-use practice before and after a change in legislation.

iv. **Model-based scenario analyses.** These can aim to forecast future forest conditions, assess resource utilization potentials and evaluate optional management strategies given different land-use scenarios (Lämås and Eriksson, 2003; Lundström and Söderberg, 1996; Sandewall and Nilsson, 2001).

For sustainable forestry or land use, the above types of analysis need to consider a broad range of goods and services (e.g. round-wood for industrial use, fuelwood, non-timber forest products, biodiversity, removals and emissions of carbon dioxide from the atmosphere, recreation, water protection, etc.). In policy development and strategic planning, NFA data also will need to be co-analysed with data and information from other sources (e.g. socio-economic data, market data and changes in legislation and policies).

Decisions based on NFA data typically concern national and subnational forest or land-use policies. The types of analyses listed above may provide background information for such decisions. In particular, the type of analyses listed under (iv) are important for identifying available options, while the analyses listed under (ii) and (iii) are important for evaluating the effects of past and present policy.

The treatment of NFA organizational issues in the following sections assumes that the organization is responsible for both data acquisition and analyses (including dissemination of results). This arrangement is generally a practical one, allowing people who use data for analyses to oversee acquisition procedures. This enables them to gain an insight into data quality issues important for the correct interpretations of analysis results. Where the NFA organization is responsible only for acquisition and analysis is undertaken elsewhere, the link between data capture and analysis will be weaker.

Recently, REDD has emerged as a potentially very powerful driver of forest inventories in developing countries. Measurement, Reporting and Verification (MRV) for REDD should typically be linked with country-based NFA activities (Herold and Skutsch, 2009). For countries involved in REDD, the development of NFA and REDD/MRV capacities should go hand-in-hand.

2.2 Organization in relation to NFA design complexity and continuity

In designing NFAs there are several options to increase the theoretical efficiency of the inventory by incorporating sophisticated statistical techniques (e.g. Schreuder *et al.*, 1993; Thompson, 1992). However, there is a clear trade-off between theoretical efficiency and simplicity of design. A simple, robust and straightforward design is important from an organizational point of view for the following reasons:

- The availability of skilled personnel within narrow subject fields is generally limited. The more complex the design chosen, the more vulnerable the organization will become with regard to dependency on key personnel.
- A simple design implicitly gives more people intellectual access to data, thereby permitting a greater number of people to perform analyses based on the NFA data.
- A simple design will allow more stakeholders to understand how forest and land-use statistics are derived, thereby establishing a better basis for

common agreement regarding the obtained results.

- Complicated designs are often adopted to reduce costs in fieldwork, but may lead to extra costs during the analysis phase since complex analysis tools are needed to analyse the data. Furthermore, there is an increased risk of erroneous results due to misunderstandings.

To summarize, in many cases a straightforward design approach is preferable over a complex but theoretically efficient design. However, the importance of simplicity should not be over-emphasized. In any case, it is important to consider the organization of the NFA and the competence level of people likely to work with the assessment during the design phase.

A closely related issue concerns the amount of variables included in the survey. Many of the issues listed above are also valid in this respect. For example, the need for training and the development of competencies will be higher when more variables are introduced in the inventory. There is also a risk that focus may be lost from the most important variables and that data quality may be reduced.

Another important design issue concerns whether NFAs should be carried out continuously (i.e. every year), averaging data over several years when estimating the current state of a particular feature, or carried out only at specific intervals. From the organizational point of view, many arguments favour a continuous approach:

- A continuous inventory allows personnel to be hired on a long-term basis. This approach would generally allow the organization to attract and retain more skilled personnel than would otherwise be the case.
- The time allocated to training is likely to decrease considerably with a continuous approach. Conversely, inventories run only at certain intervals are likely to involve greater numbers of new personnel each time the inventory is run.
- A continuous approach also encourages continuity in inventory methods and assessment techniques. This reduces the risk of surveyor-induced systematic errors in the results between different time points.
- Lastly, a low but stable budget over time may be more easily accommodated by national budgets than larger requirements at specific points in time, which may not always be obtainable.

However, there may also be drawbacks to running a continuous inventory, such as the increased difficulty of implementing changes in the NFA. Another aspect is costs and priorities. For example, in many developing countries the principal aim is to achieve the best possible work given the available project resources and time (Velle, 1995).

In the event that an NFA organization is established to run an inventory on a non-continuous basis (i.e. the organization needs to downsize between assessment periods), it may still be possible to ensure continuity by linking the NFA organization closely to a more permanent body, such as a university or a forest research institute. In such cases, the NFA activities could be linked with other periodic activities, maintaining many of the positive features of running an inventory on a continuous basis. Another possibility is to ensure that the core part of the organization is stable, concentrating on data acquisition during some periods and data analyses during others. In this case, only the field staff would be employed on a an intermittent basis.

2.3 Key issues in establishing an NFA organization

Having discussed the role of the NFA organization, this section examines some key issues relating to establishing an NFA organization.

Establishing links with users of NFA data and information is crucial. The most important stakeholders should be involved preferably

from the early stages of the organization. At later stages, the role of stakeholders may be formalized through steering committees or reference groups to the inventory and analysis activities. Such links are very important, as the overall rationale of the NFA is the delivery of information to stakeholders.

Links to competencies within the fields of resource assessment and modelling are also important. The introduction of forms of interview-based data collection underlines the importance of communication skills and social science-based techniques. It is likely that the NFA's permanent staff will be rather restricted in numbers, due to limited resources. Thus, good knowledge exchanges and links with universities, research institutes and similar organizations are a means to ensuring that the knowledge and skills needed for different parts of the NFA are available on a long-term basis. National experts may also be tied to steering groups or reference groups, broadening the potential scope of discussions at such meetings.

Accordingly, it may be advisable in many cases to establish the NFA organization in close proximity to users or established centres within relevant fields. In most countries there are stakeholders with an interest in forestry and land-use issues. In the event of conflicts or disagreements between different stakeholder groups, it is advisable to establish the NFA organization in such a way that all stakeholders can consider it to be neutral and trustworthy. This would often imply situating the organization close to research institutes or universities, rather than in close proximity to any of the major stakeholders. This may also be an argument for *not* establishing the organization within existing governmental organizations responsible for evaluating the success (or failure) of current forestry or land-use policies in the country, as the organization may not be fully objective with regard to the presentation of results. Where different government bodies are responsible for different land-use sectors (e.g forestry and agriculture), there is also a risk that separate NFA organizations may be developed, or that data collected by one organization may not used by the other, even where land-use issues concern both.

The NFA organization needs an *adequate mix of competencies* to work well. There is a need for competencies in the subject fields the NFA is established to monitor; in other words, there is a need for knowledge of which key variables should be included in the inventory, and which definitions and assessment methods to use. Such competencies may include, *inter alia*, silviculture, forest management, agriculture, biology and other issues such as socio-economics. Experts in these fields will be important both for planning the inventory and for interpreting and presenting results in an understandable manner. In addition, professionals with a strong knowledge of statistics will be needed to design the NFA, analyse results and develop functional relationships for use in scenario modelling. In particular, there is a need for specialists in sampling techniques, as well as a general need for computer specialists.

Lastly, if the country is adopting a REDD policy the development of REDD/MRV capacity and NFA capacity should be coordinated. It is probable that the REDD requirements will require countries to allocate substantial resources to MRV issues (Herold and Skutsch, 2009), and since these are clearly linked to NFA the two activities should ideally be integrated. In this case, there may be challenges involved with clearly identifying and addressing the information needs beyond the requirements of REDD.

2.4 Components of the NFA organization

This section examines the key structural components within an NFA organization. It assumes that the NFA organization is involved in strategic forestry and land-use planning at the national and subnational level, and that data acquisition and analysis activities are carried out by the same organization.

Depending on the available resources, the organization may be either a single integrated entity or a larger entity split into different units. In the latter case, different options are available. The following proposal should be seen as one among many different options:

- **A unit responsible for data acquisition.** Field staff may be hired on a permanent basis and be responsible for other issues within the organization between field campaigns. Alternatively, field staff may be hired only for actual field data collection. Another possibility is to assign field data collection entirely to contractors (although this may increase the risk of varying data quality between years). However, in all cases there is a need for a permanent core unit responsible for planning data acquisition. This unit would typically be responsible for hiring field staff, acquiring materials, planning the field campaigns, conducting assessment checks, and evaluating and enhancing the data acquisition aspect of the NFA. In the event that the NFA comprises both remote sensing and field data collection, it may be advisable to separate these aspects because of the different skills involved. Interview-based data collection requires special competencies both for data collection and analysis. It can be organized in several ways, but it is advisable to include specialists both in the central organization and in each field team.
- **A unit responsible for analyses**. Although personnel in this unit would ideally also be involved in data collection, so as to gain an insight into issues of data quality, their main responsibility would be various forms of data analysis, as well as dissemination of results. This unit will need to maintain close communication with stakeholders, so as to be able to respond to external needs.
- **Technical unit**. The core people in this unit would be computer specialists working in close cooperation with personnel from other units. In many cases, resources will be too limited to allow for a separate technical unit. In such cases, computer specialists within a research institute or similar organization may be given special responsibilities for issues relating to the NFA.

In allocating resources to different units a common mistake is to allocate too small a share to analysis and dissemination of results. This is because it is difficult to estimate accurately the work involved and predictions made during the planning phase are often overly optimistic.

3. Implementation of an NFA

The implementation phase typically starts with the planning of data acquisition and comprises a series of activities ending with data analysis and dissemination of results. Once the design of the inventory has been decided upon, it is the task of the established organization to carry out the inventory and compile the results. The implementation conditions and requirements will differ slightly depending on whether or not the inventory is run on a continuous basis. For an inventory run only at certain time intervals, the data acquisition phase may extend over several years, followed by an analysis and dissemination phase. For an inventory run on a continuous basis, each year may constitute a cycle of data acquisition and analysis. In the latter case, analyses will typically be based on data averaged over the last three to five years.

The main elements that follow remain the same regardless of the approach taken. However, the following discussion is premised on an inventory run on a continuous basis. The NFA implementation cycle, focusing on an assessment based largely on field sampling, may be presented as comprising the following steps:

i. Conversion of theoretical design into

practice

ii. Development or updating manuals for the inventory
iii. Development or updating data-capture procedures
iv. Acquisition of materials needed for the sample surveys
v. Hiring and training of staff for the data collection
vi. Data collection
vii. Independent verification of assessments
viii. Data control and compilation of databases
ix. Analyses
x. Dissemination of results.

In addition, there is a need to evaluate the entire NFA process at certain intervals and implement changes due to identified possible shortcomings and revised needs on the part of end users. The following sections discuss each aspect of the inventory implementation cycle in more detail.

3.1 Conversion of theoretical design into practice

The theoretical design of the inventory needs to be converted into practice. In terms of field sampling this involves determining the actual sample sizes and the distribution of sample units over the area to be surveyed. In many cases there will be a need for an initial stratification of the land area, for example, to allocate inaccessible areas to specific strata for handling according to separate procedures. Where digital maps and GIS are available, the work involved is often straightforward. Where maps are available only in paper form, the work involved in determining land areas and plotting sample plots according to the design may be quite substantial. In such cases, the work may need to start well in advance of actual field sampling.

Although modern GPS equipment is available in most parts of the world, maps of the areas to be sampled are still important for field teams, helping to locate the best routes to the selected plots and to identify land ownership in countries where permits must be obtained prior to visits.

3.2 Manual for the inventory

A well-written instruction manual for inventorying must be available in good time for training of field staff, before the commencement of fieldwork. To ensure high data quality, the manual should provide clear procedures and definitions for the assessments in unambiguous language.

3.3 Data-capture procedures

Several issues need to be considered when choosing between computers or forms to capture data in the field. There are many advantages to a well-functioning field computer system. Fieldwork will often be simplified, especially if definitions and assessment options are displayed. In addition, checks for valid values and simple data plausibility checks can be performed. However, significant resources may be needed to develop and maintain the system, and the use of computers will further increase the training needs of field staff.

In some cases, therefore, it may be advisable to use procedures based on field forms, although field computers (when operating well) considerably simplify fieldwork. Use of field forms will also require subsequent registration of data on computers before analysis can take place. This step may be expensive and can potentially introduce registration errors. However, field forms can function as an effective back-up system, easily accessible to the majority of personnel. Furthermore, in the case of interview-based data collection, the presence of computers may cause alienation between interviewers and interviewees.

3.4 Acquisition of materials

Forest inventories require a number of different measurement instruments, such as callipers, hypsometers and equipment for determining distance. During the last decade, traditional instruments have also been supplemented with modern alternatives based on digital technology, giving staff the option of using traditional measurement tools or investing in new technology.

General advice in this respect is to adapt to the level of technical competence in the given context, taking into consideration labour costs in relation to the increased efficiency of the new instruments. Generally speaking, modern instruments reduce the risk for errors provided they are properly used. However, they also need to be correctly maintained and when used in conjunction with advanced methodologies can render the inventory vulnerable to technical problems.

3.5 Hiring and training of staff for data acquisition

Due to limited resources, field staff may in some cases be hired only on a temporary basis during the field data collection phase. Thus, some of the personnel involved in data collection are likely to be new every year. This introduces a need for repeated and consistent training of field staff.

The issue of consistency is very important. While a gradual increase in the level of competence of field staff would seem desirable, in practice this can complicate trend assessments with the production of data of varying quality. In some cases, varying levels of systematic errors between years can be severe, and in the worst case may lead to completely erroneous conclusions regarding trends. It is, therefore, important to train and maintain the competence of field staff at a stable level (see Bell, 1998). If possible, standard procedures should be established for training and to allow assessments to be performed consistently every year.

3.6 Data collection

In many countries an important part of planning field data collection is to verify who owns or manages the land where a field plot will be situated. There are several reasons for this. First, it may be necessary to obtain permits to access the land. Second, ownership information may be important for the analyses. Third, it is important to identify the stakeholders before interviews can take place.

During field data acquisition it is important to maintain continuous contact with the field teams. One method is to arrange for specific people to visit the field teams during their work.

During the actual work, GPS equipment generally functions as a good (and rather cheap) complement to field maps, allowing teams to accurately locate plots in the field. This is of particular importance when permanent plots are to be established or revisited. However, when planning procedures to establish the exact location of field plots, it may be advisable to employ a form of randomization, rather than relying on GPS all the way to the plot centre. This is because of the risk of systematic errors in plot locations resulting from poor GPS-receiving conditions in dense patches of forest.

Permanent plots will need to be established in a manner that allows them to be easily found for re-inventorying at a later date. It is important that any marks introduced for this reason are very discreet, so that the plot locations do not become known to land managers. Otherwise, there is a risk that the permanent plots within the NFA will develop in a manner different from other land areas, biasing the results of the NFA.

From the organizational point of view, a variety of administrative procedures need to be established to ensure that correct salaries and reimbursements are properly paid. Moreover, proper procedures for submitting data from the field to the NFA office need to be established to avoid loss of information.

3.7 Assessment checks

Assessment checks should be considered an integral part of any field data acquisition campaign within an NFA. By making clear that a certain percentage of plots will be revisited and checked by a control team, the ordinary field teams have an incentive to maintain "good practice" during their work. This may be the most important reason for performing assessment checks. In addition, assessment checks allow insights into data quality issues that would otherwise not be possible.

By analysing data from the assessment check for certain types of variables, it is possible to discover actual errors committed during the inventory. This includes variables such as the number of trees on a plot and tree diameters. For other variables, the control team must make subjective assessments. In this case, the assessment checks will highlight the variability among different crews, rather than the deviation of the standard team from the true value.

In the case of very ambitious assessment checks, it may be relevant to adjust the original estimates based on the results from the check. However, this will introduce additional complexity to the NFA.

3.8 Data control and compilation of databases

In addition to consistency checks (preferably already performed in the field) and assessment checks, it is important to perform completeness tests at the final stage of data compilation to ensure that all data have been collected. Moreover, checks based on logical relationships between different variables may be conducted.

3.9 Analyses

As noted above, the analyses may take different forms. As part of the inventory cycle every year, it may be advisable to include only certain standard results. The main reason is that integrated analyses including scenario analysis are very demanding and would therefore be carried out only at certain intervals. It may also be wise to focus on different types of analyses for different years.

In the event that the NFA is based on a complex design, standard procedures for assessing state or change could be implemented based on the NFA databases.

3.10 Dissemination of results

The final stage of the inventory cycle is the dissemination of results to stakeholders. There are several options here. Although this section does not elaborate on these in detail, a few remarks are warranted.

When an NFA is newly established, there is often a need to make stakeholders aware of its existence in order to discuss how the data can be used and in what form the results should be presented. Therefore, it is not advisable to wait until all results are finalized before starting dissemination. Many inventory projects lead to substantial amounts of data, published in thick reports, which are rarely used. Careful planning of continuous dissemination of results may prevent this.

4. Concluding remarks

The key message of this chapter is the importance of considering NFA organization and implementation. The theoretical issues associated with NFA design are often emphasized; however, in practice in most cases the performance and reliability of an NFA will depend on a number of issues relating to implementation, which in turn depends on organization. Strict procedures need to be established in all phases to avoid surveyor or analysis-induced errors that may dramatically reduce the usability of information produced by the NFA. For example, varying systematic error levels between years may lead to severely erroneous policy conclusions. Such errors can be avoided through careful organization of the NFA and rigorous implementation.

Lastly, REDD/MRV is likely to be a major driver of forest inventory in many countries

in the future. In this context, it is important to stress that proper coordination between organization and capacity-building for NFA and MRV would be beneficial.

Self-study exercises

1. What role does the NFA have in your country? (Discuss and answer this question in relation to the issues raised in section 2, p. 14)
2. Which organizational and implementational aspects of the NFA point towards using simplicity as a guiding principle for design, data collection and analysis procedures?
3. List and briefly describe the important steps in the implementation of the NFA cycle.
4. In your country, what existing "capacity centres" would be important partners for the NFA in the event that all the required capacities are not available in-house?
5. In your country, which environment would be adequate for the NFA organization? (In the event that that has already been established, discuss the advantages and disadvantages of the current arrangement.)

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Sampling designs for national forest assessments

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THIS CHAPTER DISCUSSES THE FOLLOWING POINTS:

- Definition of a population for sampling purposes.
- Selection of the size and shape for a plot configuration.
- Distinguishing among simple random, systematic, stratified and cluster sampling designs.
- Methods for constructing sampling design.
- Estimating population means and variances.
- Estimating sampling errors.
- Special considerations for tropical forest inventories.

Abstract

National forest assessments are best conducted with sufficiently accurate and scientifically defensible estimates of forest attributes. This chapter discusses the statistical design of the sampling plan for a forest inventory, including the process used to define the population to be sampled and the selection of a sample intended to satisfy NFA precision requirements. The team designing a national forest inventory should include an experienced statistician. If such an expert is not available, this section provides guidance and recommendations for relatively simple sampling designs that reduce risk and improve chances for success.

1. Introduction

The sampling design chosen to support the technical programme used for an NFA requires a theoretical basis that can be implemented on the ground (see chapter on *Organization and Implementation, p. 13).* Understanding the basic concepts of statistical design and estimation methods is a key component of the overall process for information management and data registration for NFAs (see chapter on *Information management and data registration*, p. 93).

1.1 Objectives

The goal is to estimate the condition of forests for an entire nation using data collected from a sample of field plots. The basic objectives of an NFA are assumed to be fourfold: (i) to obtain national estimates of the total area of forest, subdivided by major categories of forest types and conditions, as well as the numbers and distributions of trees by species and size categories, wood volume by tree characteristics, non-wood forest products, estimates of change in these forest attributes and indicators of biodiversity; (ii) to obtain sufficiently precise estimates for selected geographic regions such as the nation, subnational areas, provinces or states and municipalities; (iii) to collect sufficient kinds and amounts of information to satisfy

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international reporting requirements; and (iv) to achieve an acceptable compromise between cost and precision, and geographic resolution of estimates.[1]

Assumptions and simplifying constraints

Several assumptions underlie the discussion that follows: first, that expert statisticians experienced in designing natural resource inventories and analysing the data are not available; second, that ancillary data in the form of maps depicting features such as ecological regions, land cover, soils, elevation, political and administrative boundaries, and transportation systems are available; and third, that models for predicting attributes such as individual tree volumes from basic tree measurements are available. Even on the basis of these assumptions, a full discussion of all sampling design possibilities for an NFA is beyond the scope of this section. Thus, three constraints have been imposed: first, this chapter presents only relatively simple, multipurpose designs that can be used reliably with local expertise; second, the discussion is limited to designs that are flexible, yet reduce risks of bias and loss of credibility; and third, there is a focus on designs that feature equal probability samples, or in the case of stratified designs, equal probability samples within strata.

1.2 Why use sampling?

The most precise description of a population comes from accurate measurements of each member of the population, otherwise known as a census. However, a typical census is very difficult to undertake because of cost and logistical problems. Imagine trying to measure every tree in a 1 million hectare forest. Instead, a sample measures a portion of the population – in forestry this is usually a very small portion. Estimates based on data collected from the measured sample are then extrapolated to the entire population, the majority of which has not been measured.

This can be thought of as "guessing" or "estimating" the condition of a population based on sampling a few members of that population. If the sample is representative of the entire population, then the estimate will be accurate and less likely to deviate from the true population value. Otherwise, estimates will be inaccurate and misleading – a situation that may not be known because the true condition of the whole population will remain unknown. The best possible approach is to increase the chances of measuring a representative sample. This can be done by using scientifically rigorous rules to select the sample, maximizing the number of sample units observed or measured, and minimizing the errors in measuring each sample. It is not difficult to produce data. It is much more challenging to produce accurate data with known reliability that will be used to help make important decisions.

1.3 Defining the population

Scientifically defensible estimation of population attributes is based on a formal body of mathematical theory, which must be respected if it is to be used to defend the accuracy of sample-based estimates. The careful selection of a sampling frame, plot configuration and sampling design are crucial steps in the process and cannot be accomplished independently of each other. Each decision has an impact on the others. The mathematical theory begins with a precise definition of the population for which attributes will be estimated. For example, for a municipality of 5 million ha of which 1 million ha comprises forest, the statistical population could be described in several different but logical ways:

- Thousands of tree-stands and non-forest polygons
- Tens of millions of potential 0.1 ha sampling plots
- Ten million remotely sensed 30 m x 30 m pixels
- Billions of trees
- An infinite number of points.

1 See chapter on *Observations and measurements*,- Section 2, p. 42

There is no one best definition of a population for forest inventories. The key issue in basic applications of forest sampling is to define precisely the geographic boundaries of the targeted population, such as all lands, both forest and non-forest, within a nation that are outside the geopolitical boundaries of urban areas. It is not uncommon to discover that portions of a target population cannot be sampled. Examples include areas that are remote and inaccessible or unsafe to access. These areas should be identified precisely in a cartographic form, even though the true boundaries might not be obvious, and excluded from the sampled population. Scientifically defensible estimates must be limited to the sampled population only.

1.4 Choosing a sampling frame

Three terms can be distinguished: sampling frame, sampling design and plot configuration. *Sampling frame* refers to the set of all possible sample units; *sampling design* refers to the selection of a subset of sample units to represent the population; and *plot configuration* refers to the size, shape and components of the field plot.

Some advantages are gained with a sampling frame that considers a forest to be an infinite population of points. One approach to sampling with this type of sampling frame is to use the popular Bitterlich plot, which is efficient for estimating variables correlated with tree size. Alternative point-based plot configurations measure a support region and impute its attributes to a point. When near a boundary or stand edge, a point is more easily assigned to one side or the other, whereas plots with different designs can straddle edges or boundaries. A recommended approach is to consider the forest population to be an infinite set of points and to use physical measurements in a support region to describe conditions at a sample point.

1.5 Choosing a plot configuration

The plot configuration consists of the plot size and shape and determines the variables to be measured at each sample plot location. Choices for plot configurations include variable area plots, fixed-area plots, subdivisions of plots into subplots and cluster plots, all of which require size and shape considerations. Variable area plots using Bitterlich sampling are particularly effective for obtaining precise estimates of forest attributes relating to tree size. Fixed-area plots, while not necessarily optimal for any particular forest attribute, are an excellent compromise when sampling is intended to produce estimates of a wide variety of forest attributes, and tend to be more compatible with ancillary data. Cluster sampling reduces travel between plots while providing a sufficient number of plots. The optimal shape and size may be addressed using sampling simulation and prior information, although circular plots are often used in forest inventories.

Issues concerning the selection of a plot configuration are also discussed in the chapter on *Observations and measurements, p. 41.*

1.6 Measuring sample plots

The chapter on *Observations and measurements* summarizes the major considerations relevant to measuring sample plots. For more detailed information, see Schreuder *et al.* (2004). This section discusses two aspects of this issue: the use of remotely sensed data for measuring plots and temporary versus permanent plots.

First, remotely sensed data from medium-resolution satellites and high-altitude aerial photography (1:24 000 to 1:60 000 scales) provide cost-effective measurements for coarse indicators of forest conditions, mostly forest area changes. However, most measurements of detailed forest conditions are impossible with these sensors (see chapter on Remote sensing, p. 77). More detailed measurements of forest conditions may be obtained with low-altitude aerial photography

and sensors such as Lidar. All these sensors are currently expensive and have narrow fields of view that are not currently capable of producing border-to-border coverage of an entire nation. However, in principle, these sensors could be used to measure a sample of locations in a national survey. For example, it may be cost efficient to measure a plot initially with data from a remote sensor to determine if the plot has accessible forest land cover or forest land use. If not, field crew visits to such locations may not be warranted.

Second, estimating changes and trends in a country's forests is often an important part of an NFA. If the locations of sample plots are sufficiently documented, then the same plots can be remeasured over time to obtain more precise estimates of forest change, such as tree growth, mortality, harvesting, regeneration, and changes in the areas of forest conditions and land-use categories. Remeasurement of plots increases estimation efficiency and contributes to better understanding of the components of change. However, if permanent plots are used, their locations must be very accurately documented. To do this, researchers can drive a pin into the ground at the centre or corner of a plot, and carefully document how to find the pin from a convenient starting location, perhaps several kilometres distant. The pin should be hidden from normal view to keep the plot truly representative of thousands of hectares that will never be measured. A sample plot will not be representative if it receives special treatment, such as protection from harvesting or other disturbances. An obvious pin in the ground could also influence how others treat the location.

Although remeasurement of the same trees produces the most precise estimates of change, this approach is more costly because the same plot centres and trees must be relocated at the time of each measurement. Alternatives for estimating change from temporary plots include estimation of tree growth from increment borings, and gross estimation of forest area and volume change by comparing independent estimates obtained from measurements of different sets of temporary plots at different points in time. However, harvest, mortality and regeneration are difficult to estimate using data from temporary plots. Thus, where possible, it is recommended to use permanent plots or a combination of permanent and temporary plots (e.g. Ranneby *et al.*, 1987).

2. Sampling design

There are two general sampling approaches: subjective or purposive sampling and probability sampling. Subjective sampling attempts to use professional judgement to select sample units believed to be representative of the entire population. These units are often convenient to measure, which reduces cost. Although data gathered in this way accurately describe the conditions on the sampled sites, they may not accurately characterize the entire population. Supporters of subjective sampling trust the ability of experts to select a representative sample and argue that this approach is good enough for practical purposes. In some simple situations, this may be true. However, some users of the data may lack the same confidence in the experts. Expensive data can become worthless because the sampling design is not sufficiently robust under scientific criticism. In addition, convenient sampling sites are often near roads, which are frequently associated with unique landforms, land uses, management histories and landscape patterns. Are such sites truly representative of the entire population? The answer is debatable. It is far easier to discredit the accuracy of population estimates from a subjective sample than prove otherwise.

Probability sampling replaces subjective judgements with objective rules based on known probabilities of selection for each member of a population. For example, if a 1 million ha forest comprises a population of 10 m x 10 m plots, there would be 100 million of those plots in the population. The selection of one of these plots at random amounts to

a probability of 1/100 000 000. Selection of a simple random sample of 1 000 plots to estimate conditions in the entire 1-million ha population would give each member of that population a probability of selection of approximately 1 000/100 000 000=1/100 000, and each plot measured in the sample could be seen as representing 99 999 other unmeasured plots. The important lesson is that probability sampling is an objective method with precise rules and a mathematical foundation for estimating population attributes based on a sample. The probability that an expert will select any one potential sample plot is unknown, and the mathematics of subjective sampling cannot be applied in a scientifically defensible way. Thus, this chapter recommends probability rather than subjective sampling, and further recommends equal probability sampling in which possible sampling unit locations have equal probabilities of selection for the sample.

2.1 Selecting a probability sampling design

Many of the difficulties associated with selecting a sampling design arise from two factors: first, sampling units are distributed in space and observations of them may be spatially correlated; and second, different sampling designs have different costs. Spatial correlation among observations of variables of interest strongly influences selection of sampling designs. Ecological, climatic and soil factors, and forestry management practices, cause observations from plots that are near to each other to be, on average, more similar than observations from plots that are farther apart. The result is that, in a strict sense, construction of a completely optimal sampling design is an impossible task because the numerous NFA-measured and derived variables vary quite differently in space. Thus, because optimal sampling designs are different for different variables, optimization may necessitate a focus on minimizing the standard error of a single important variable, such as wood volume, or on a weighted function of the standard errors for a small number of variables. One partial solution is to minimize the effects of spatial correlation by establishing sampling locations as far apart as possible. This also accommodates the fact that sample plot observations that deviate more from each other bring more information to the sample. In forest sampling, this often suggests hexagonal sampling designs. The primary sampling costs are attributed to travelling to and from the sampling unit location and measuring the unit. These costs, in turn depend on the structure of landscape and forests, measurements to be taken, and topographic, economic and transportations conditions.

A common starting point in selecting a sampling design is knowledge of the acceptable upper bounds for standard errors of estimates and an upper bound for cost. Optimizing the sampling design, given the sampling frame and plot configuration, involves selecting a procedure for spatially distributing the sampling unit locations in such a way that standard errors are minimized, while not exceeding the total allowable costs. Sometimes this will not be possible, and compromises may be necessary.

2.2 Simple random sampling

Figure 1a shows a simple random sample with sample plots placed randomly within the sampled population. Although there are spatial clusters and voids in the plot distribution, this remains a valid probability sample. The geographic coordinates for each sample plot in a random sample may be selected with a random number generator with the allowable coordinates restricted to the sampled population. Otherwise, no consideration is given to safety, difficulty of measuring plots or travel to and from plot locations. This is the least risky equal-probability sampling design, but it is also usually the least efficient with respect to both cost and the precision of estimates,

partially because of spatial correlation among observations.

2.3 Systematic sampling

A systematic sample uses a fixed grid or array to assign plots in a regular pattern (Figure 1b). The advantage of systematic sampling is that it maximizes the average distance between plots and therefore minimizes spatial correlation among observations and increases statistical efficiency. In addition, a systematic sample, which is clearly seen to be representative in some sense, can be very convincing to decision-makers who lack experience with sampling. Systematic samples may be based on rectangular grids or hexagonal arrays. For example, a sample plot could be established at the intersections of a 2 km x 2 km grid. A random number is used to select the starting point and orientation for this grid, but no other random numbers are required. This sampling design is common in forestry. The greatest risk is that the orientation of the grid may, by chance, coincide with or be parallel to natural or man-made features, such as roads or gravel ridges resulting from melting glaciers. For very large geographic areas, orientation of gridlines along lines of longitude should be avoided. In higher latitudes the converging nature of these north-south gridlines may cause sample plot locations to be closer together in higher latitudes than in lower latitudes. Sampling designs based on hexagonal arrays alleviate this problem (White *et al.*, 1992).

Systematic unaligned sampling designs combine features of both simple random and systematic sampling designs. With these designs, a sample plot is assigned to a randomly selected location within each grid or array cell (Figure 1c).

2.4 Cluster sampling

For practical reasons, such as increasing cost efficiency and reducing field crew travel,

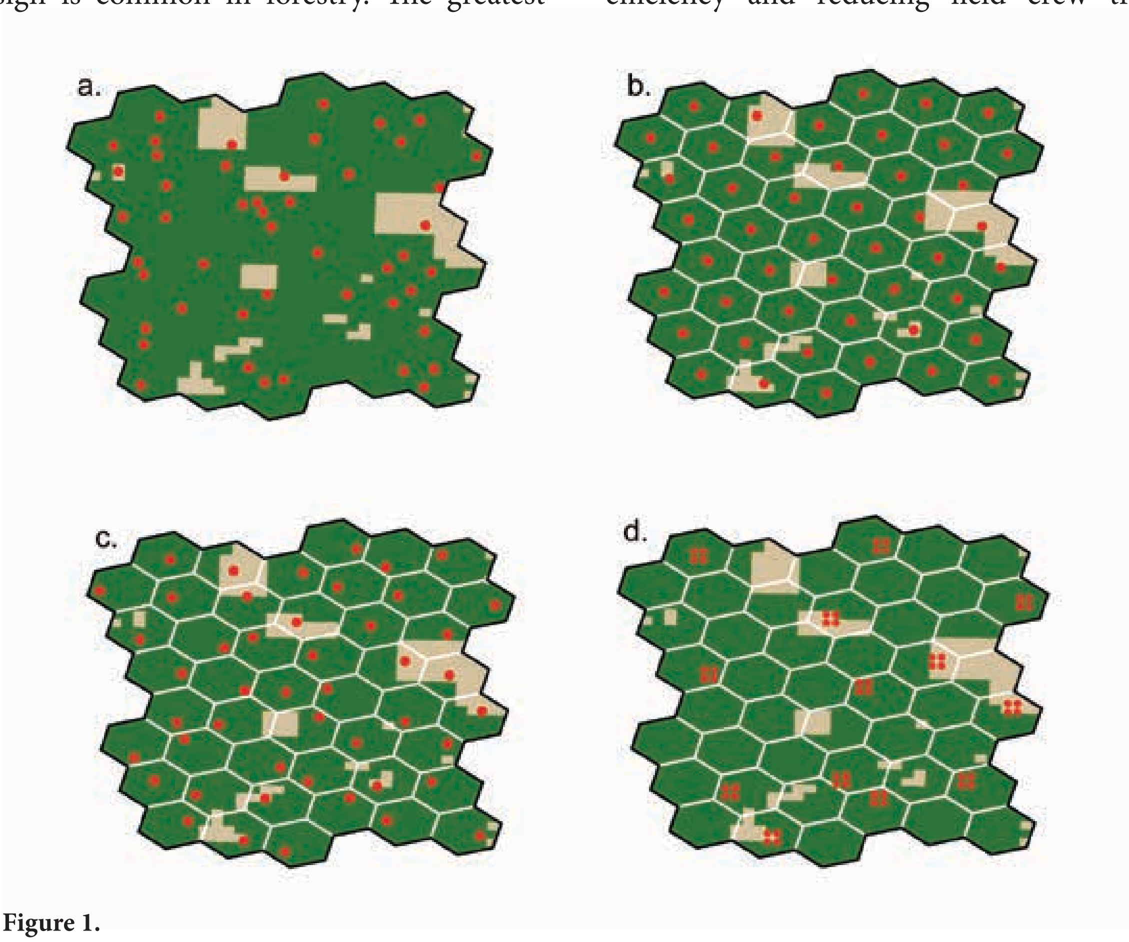

Figure 1.
(a) simple random sampling design; (b) aligned systematic sampling design; (c) unaligned systematic sampling design; (d) unaligned, clustered, systematic sampling design with the same number of plots but grouped into clusters

sample plots may be organized into clusters, thus leading to *systematic cluster sampling* and *stratified systematic cluster sampling*. In systematic cluster sampling, the clusters are distributed throughout the population using grids or polygons such as hexagons.

Several questions are relevant when planning a cluster-based sampling design: (i) what is the spacing between clusters? (ii) what is the shape of the cluster? (iii) what is the number of plots per cluster? and (iv) what is the sample plot configuration? To answer these questions, preliminary information about the spatial distribution and correlation of the variables of interest is needed. Correlation as a function of distance between field plots, estimated using variograms, can be used to compare the efficiencies of different sampling designs.

2.5 Stratified sampling

Stratified sampling entails first dividing the population into non-overlapping subpopulations called *strata* that together comprise the entire population, and then drawing an independent sample from each stratum. If the sample in each stratum is a simple random sample, the whole procedure is described as *stratified random sampling*. Numerous reasons may be given as justification for stratified sampling (Cochran, 1977; Schreuder *et al.*, 1993). First, stratification is used to increase the precision of population estimates. To understand the potential gain in precision that may be achieved with stratification, some notation and formulae are necessary. With simple random sampling (SRS), the estimate of the population mean is

$$\bar{y}_{SRS} = \frac{1}{n}\sum_{i=1}^{n} y_i \quad , \qquad [1]$$

and the estimate of the variance of the mean is

$$var\left(\bar{y}_{SRS}\right) = \frac{s^2}{n} \quad , \qquad [2]$$

where n is the sample size, y_i is an observation, and

$$s^2 = \frac{1}{n-1}\sum\left(y_i - \bar{y}\right)^2 \quad , \qquad [3]$$

is the sample estimate of the population variance. Cochran (1977) provides basic formulae for stratified estimation. Ignoring finite population correction factors and estimation errors in stratum weights, an unbiased estimator of the population mean and variance are,

$$\bar{y}_{Str} = \sum_{h=1}^{L} W_h \bar{y}_h \quad , \qquad [4]$$

and

$$var\left(\bar{y}_{Str}\right) = \sum_{h=1}^{L} W_h^2 \frac{s_h^2}{n_h} \quad , \qquad [5]$$

where

$$\bar{y}_h = \frac{1}{n_h}\sum_{j=1}^{n_h} y_{hj} \quad , \qquad [6]$$

$$s_h^2 = \frac{1}{n_h - 1}\sum_{j=1}^{n_h}\left(y_{hj} - \bar{y}_h\right)^2 \quad , \qquad [7]$$

are the within stratum means and variances, respectively; h=1, 2, …, L denote strata; j denotes observations within strata; n_h denotes the number of sample observations within the h^{th} stratum with $n_1+n_2+\ldots+n_L=n$; and Wh is the stratum weight representing the proportion of the population in the h^{th} stratum. The effects of stratification and stratified estimation on precision are often assessed using relative efficiency, *RE*, defined as,

$$RE = \frac{var\left(\bar{y}_{SRS}\right)}{var\left(\bar{y}_{Str}\right)} \quad , \qquad [8]$$

where RE>1 indicates a beneficial effect. Relative efficiency may be interpreted as the increase in the overall sample size necessary to achieve the same precision using estimation based on simple random sampling, as is achieved through using stratification and stratified estimation. From a quantitative perspective, precision gains are realized when

variances of estimated stratum means are substantially less than the variance of the overall estimated mean (i.e. $\frac{s_h^2}{n_h} < \frac{s^2}{n}$) and/or when strata with large $\frac{s_h^2}{n_h}$ represent small proportions of the population (i.e. when W_h is small). From a qualitative perspective, precision gains are realized when heterogeneous populations are divided into more homogenous subpopulations. This typically means that the strata have substantially different means, variances or both.

A second reason for stratification is that it may contribute to avoiding bias, depending on the estimator selected. For example, NFA field crews generally are granted access to plot locations on publicly owned lands. However, if the permission of private landowners is required to measure sample plots on their lands, inevitably some will deny access. In extreme cases, the ratio of privately owned to publicly owned plots in the accessible portion of the sample may be considerably less than the ratio of privately owned to publicly owned forest lands in the population. If the species compositions and/or management practices are substantially different on privately owned and publicly owned forest lands, bias may occur. One solution is to stratify lands by ownership, thus leading to independent sample estimates for the two ownership strata (McRoberts, 2003).

A third reason for stratification is to accommodate different sampling protocols or different estimation procedures for different subpopulations. For example, a substantial portion of sampling costs may be attributed to travel to and from plot locations. If data from remote sensors may be used to determine that some plots are located on non-forest land, then travel costs may be substantially reduced by not sending field crews to these plot locations. As a result of the different measurement technique, however, a different estimator may be required for these strata.

The greatest benefits of stratified estimation are realized when the population is stratified and stratum sample sizes are determined before sampling is conducted. The process of determining stratum sample sizes or, equivalently, allocating samples to strata, may be accomplished in several different ways and for several different purposes. Frequently, samples are allocated to strata in proportion to some attribute of the strata. An easily implemented approach is to allocate sample plots to strata in proportion to strata sizes. If simple random or systematic sampling is used within strata, then this approach leads to equal probability samples within strata, which may simplify estimation. However, with this approach, the variances of stratum means may differ greatly. If comparably precise estimates of stratum means are desired, then samples may be allocated to strata in proportion to stratum variances. A potential disadvantage of this approach is that good estimates of stratum variances are necessary before samples are allocated to strata. Finally, it may be that estimates of means for some strata are more important than others. In this case, samples may be allocated to strata in proportion to a subjective assessment of strata importance.

Often the sampling objectives prohibit stratified random sampling. For example, a systematic sampling design may be used as a means of optimizing the precision of estimates for multiple variables simultaneously. Even though the greatest benefits of stratification may not be realized for any particular variable, the beneficial effects of increasing precision and precluding estimation bias may still warrant post-sampling stratification and stratified estimation. Thus, even if stratified sampling is not used, consideration of post-sampling stratified estimation is recommended because large increases in precision may often be realized with little additional cost or effort.

Almost any source of data can be used to create strata as long as two tasks can be accomplished in a consistent manner. First, stratum weights, calculated as the proportion of the population represented by each stratum,

must be determined. Second, each plot must be assigned to one and only one stratum. The increasing availability of diverse thematic digital data layers opens vast possibilities for sources of data that can be used to create strata. In addition, the increasing availability of geographic information systems (GIS) greatly simplifies accomplishment of the two tasks. One popular choice of stratification data is land cover classifications from which aggregated forest and non-forest classes may be constructed and used as strata (McRoberts *et al.*, 2002). Using a GIS with such a layer greatly simplifies the two stratification tasks. Within the GIS, each mapping unit of the land cover classification is assigned to a stratum based on the class assigned to the mapping unit. Calculation of stratum weights is then simply a matter of using GIS functionality to determine the total area of all mapping units assigned to the same stratum and dividing by the total area of the sampled population. A plot is assigned to the stratum of the mapping unit containing its centres. Other choices of digital data layers that can be used to create strata include, but are not limited to, soil maps, climate division maps, ecological provinces, administrative boundaries, ownership maps and land management units.

2.6 Ratio estimators and Matérn's error estimators

Although a discussion of statistical estimators is provided elsewhere in this chapter, or may be obtained from Schreuder *et al.* (2004), the importance of selecting estimators consistent with the sampling design in order to obtain valid variance estimates should be noted. With systematic and cluster-based sampling designs it is particularly important that estimators properly account for possible spatial correlation among observations. Because of their utility with sampling designs that must accommodate spatial correlation, this section provides a brief discussion of Matérn estimators (Matérn, 1960).

Since forest inventory estimates are frequently either means or totals for either area or volume, the relevant derived variables in forest inventory are often of the form

$$M = \frac{X}{Y} \quad , \qquad [9]$$

where X and Y are expectations of random variables, x and y. As an example, consider estimation of mean forest area per land-use stratum for sample plots that may intersect multiple strata, all within the category of forest land. One method for accommodating this phenomenon that is particularly useful with point sampling is to use the information from the centre point only. Let x_i=1 when the centre point of the plot belongs to the stratum in question and x_i=0 otherwise, and let y_i =1 when the centre point is on forest land and y_i =0 otherwise. Then the ratio estimator for mean area is

$$m = \frac{\sum_{i=1}^{n} x_i}{\sum_{i=1}^{n} y_1} = \frac{\bar{x}}{\bar{y}} \quad , \qquad [10]$$

where n is the number of sampling units. Let E(.) denote statistical expectation; then,

$$E(m) \approx \frac{E\bar{x}}{\bar{Y}} = \frac{\bar{X}}{\bar{Y}} = M \quad , \qquad [11]$$

means that m is approximately unbiased when n is large.

The estimation of standard errors is complicated by spatial correlation that may arise from trend-like changes in variables and either systematic or cluster sampling. Matérn (1947; 1960) suggested the error variance, $E(m\text{-}M)^2$, as a measure of the reliability of the estimator and also proposed a variance estimator. Let i denote field plots; let r denote clusters of field plots; and consider the cluster residuals z_r=my_r, where $x_r = \sum_{i \in r} x_i$ and $y_r = \sum_{i \in r} y_i$.

Assume that the residuals form a realization of a second order stationary (weakly stationary) stochastic process. The variance of the process can be estimated by means of quadratic forms $T = \sum_r \sum_s c_{rs} z_r z_s$,

where $c_{rs} = c_{sr}$, $\sum_r \sum_s c_{rs} = 0$ and

$\sum_r c_{rr} = 1$,

where r and s both refer to clusters of field plots. Estimators of this form are unbiased if the process z is spatially uncorrelated and conservative if the process is positively correlated (Matérn, 1960). This approach has been used in the Swedish and Finnish inventories (cf. Ranneby, 1981; see also Tomppo *et al.*, 1997, and Heikkinen, 2006) and is applied by sampling strata as follows. Within each stratum, the group g of four field plot clusters (r_1, r_2, r_3, r_4) is composed in such a way that each cluster belongs to four different groups (Figure 2).

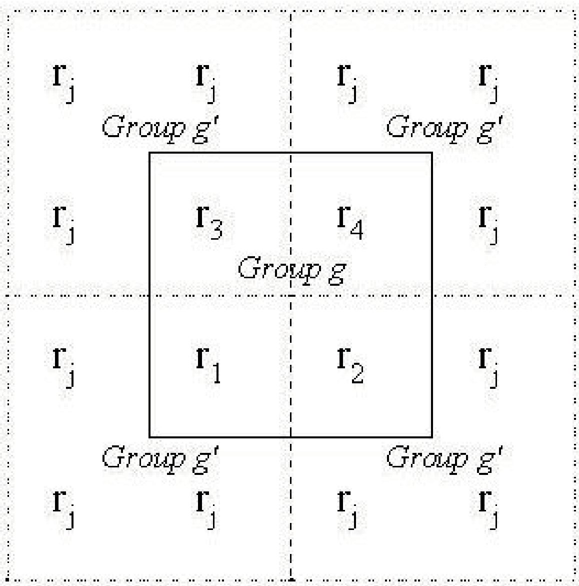

Figure 2.
Groups of clusters and clusters of sample plots.

The deviance of the cluster mean, $\bar{y}_r$, from the stratum mean $\bar{y}$ is computed for each cluster r. Denote $zr=(\bar{y}_r-\bar{y})n_r$, where n is the number of relevant sample points in cluster r (for this example, n_r=4). The weights $c_{r1} = c_{r4} = c_{r2} = c_{r3}$ = ½ are often used. The quadratic forms can then be expressed as $T_g = (z_{r1} - z_{r2} - z_{r3} - z_{r4})^2/4$ and the resulting standard error estimators for each stratum are

$$s = \frac{\sqrt{k \sum_g T_g}}{\sum_i y_i} , \qquad [12]$$

where g denotes a group of clusters in the stratum, i denotes plots in the stratum, and k is the number of clusters in each cluster group (for this example, k =1). The standard error estimators for the entire study area can be obtained by combining the stratum-specific estimators with the usual formula for stratified sampling (eqs. [4] and [5]). This procedure is relevant for strata having large numbers of field plots, preferably at least several hundred.

3. Sample size

Determination of sample size is one of the most important steps in constructing a sampling design. If the sample is too small, then uncertainty will be great; if the sample is too large, then the cost will be unnecessarily high. It is possible to quantify the expected confidence in future estimates made from a valid probability sample. As the number of sample plots increases, the variance of the estimation error decreases, the precision of the estimate increases, and more confidence can be placed in the estimate. Usually, the exact value of the estimate is known but not the true condition of the forest. With probability samples, the probability that an estimate is within a specified distance from the true value may be determined. These are the roles of the "confidence interval", an estimated range of proportions likely to include the true, but unknown, proportion of forest, and the "confidence coefficient", the probability that similar confidence intervals constructed using different samples will contain the true proportion of forest.

The simplest case is that of estimating proportions with a simple random sample,

such as estimating the proportion of a nation that is forested. For example, an NFA covers a sampled population of 5 million ha, and in a simple random sample with n=1 000 plots, 400 are forested. The estimated proportion of forest is 40 percent. What level of confidence can be placed in this estimate? If a confidence coefficient of 80 percent is acceptable, for 80 sample plots the true but unknown percentage of forest is within the confidence interval. From available tables and figures (Czaplewski, 2003), with n=1 000, and an estimate of 40 percent forest, the confidence interval is 38.0 to 42.0 percent. As another example, suppose that a rare forest type exists in the population, but the exact amount is not known. However, none of this rare forest was observed in the simple random sample of n=1 000 plots, and the estimated percentage of the nation in this rare forest condition is 0. For the same 80 percent confidence coefficient, the confidence interval for this estimate is 0.0 to 0.2 percent. Thus, the estimate of the area of this rare forest type in the entire 5-million ha nation is 0 ha to 10 000 ha. The final example is a 100 000 ha municipality for which measurement of a sample of n=20 of the 1 000 plots reveals that 18 are forested. The estimate for this municipality is 90 percent forest cover with a confidence interval of 75.5 percent to 97.3 percent, or 75 500 to 97 300 ha. Other calculations of sample sizes are possible with interactive "sample size calculators", available online. These examples demonstrate that accurate national estimates for common types of forest cover are possible with relatively few sample plots. However, larger sample sizes are often needed if the NFA requires estimates of rare forest types or small portions of the nation. It is the sample size that determines the precision of estimates in an NFA, not the size of the entire sampled population.

Determining the required sample size requires an estimate of the standard deviation of the differences between individual plot-level values and their average value. This standard deviation may be estimated with a pilot study or inventory that measures a small sample of forest plots to determine the variability among them. For example, assume the pilot inventory includes 60 plots, and wood volume is measured on each plot. Further, suppose that the mean volume is =100 m^3/ha, the variance among plots is =2 500 m^3/ha^2, and the standard deviation is =50 m^3/ha. If observations from the pilot plots are normally distributed, about 1/6th of the plots will have (100 - 50)=50 m^3/ha or less, and another 1/6th of the 60 plots will have 100 + 50=150 m^3/ha or more. Assume the precision requirement for the NFA is to estimate mean wood volume per hectare to within a ±5 percent "tolerance" or "maximum allowable difference" (Dmax=0.05) with a 66 percent confidence coefficient. The required sample size n is approximately 100 sample plots.

$$n = \left(\hat{s} \big/ \hat{\bar{x}} D_{\max} \right)^2 = \left(50 \big/ (100 \times 0.05) \right)^2 = 100 \quad ,[15]$$

If this NFA precision requirement is for the entire nation, then 100 sample plots are sufficient. If this NFA accuracy precision is for each of 10 subnational units, then a total of 1 000 sample plots is necessary. Sample sizes increase greatly as the acceptable tolerance becomes smaller. A tolerance of ±1 percent would require the sample size to increase from n=100 to n=2 500 sample plots (eq. 15) in this example. The required sample size increases for larger confidence coefficients. For example, it requires four times more sample plots to improve precision from a 66 percent confidence coefficient to the 95 percent level. More exact and detailed calculations of required sample sizes are possible with the aforementioned interactive sample size calculators.

4. Comparing sampling designs

An effective way to compare sampling designs is via simulation if a forest area model is available. The model may be obtained from a previous inventory or from satellite image-based estimation of variables of interest.

An example of the standard errors obtained from sampling designs for estimating mean growing stock volume is shown in Figure 3. The test site is in north Finland and has a land area of 6.47 million ha, a forest land area of 4.19 million ha, and a mean volume on forest land of 52.7 m^3/ha.

A pixel level, border-to-border forest map has been produced using field data from the preceding inventory, satellite images and digital map data (Tomppo, 2004; Tomppo and Halme, 2004). Satellite images of different resolution provide one information source, in addition to existing maps. A pilot inventory may also be used to collect information for planning the final sampling design. Representative subareas can be selected from the population where pilot inventories may be conducted. However, these pilot inventories must be acknowledged and accepted as less than optimal. In addition, new sampling designs can be created using information from previous inventories, as has been the case in countries where forest inventories have been conducted since the 1920s and 1930s (e.g. Ilvessalo, 1927).

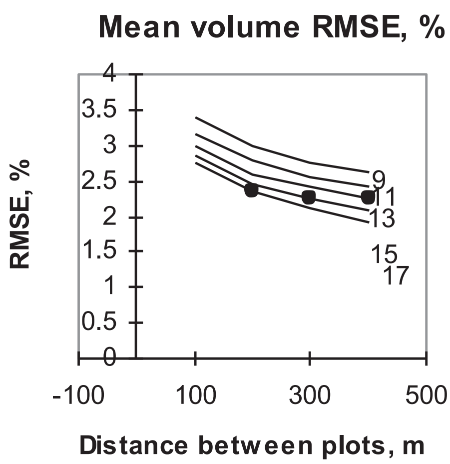

Figure 3. Standard errors based on sampling simulations with different distances between field plots and with numbers of plots per cluster ranging from 9 to 17.
Note: The distance between clusters is 10 km.
Source: Tomppo *et al.*, 2001; constructed by Helena Henttonen.

5. Sampling considerations for tropical forest inventories

In recent years, concern for the effects of climate change and actions to mitigate those effects have motivated intense interest in forest inventories in tropical countries for purposes of estimating carbon and carbon change. Such inventories, often characterized as Measurement, Reporting and Verification (MRV) systems when targeted to REDD purposes, are similar to national forest inventories (NFIs), although the MRV emphasis may be restricted to biomass-related variables, and the MRV population of interest may be restricted to lands that are subject to human-induced greenhouse gas emissions. However, because of the similarities between MRVs and NFIs, tropical developing countries often design their NFIs so that they can also serve as MRVs, or design their MRVs in such a manner that they can easily be extended to a complete NFI. Thus, the guidance articulated below pertains equally to MRVs as to NFIs.

By definition, a monitoring programme includes emphasis on change and trends. In addition, in recent years NFIs have come to place increased emphasis on change and trends. Therefore, selection of plot configurations, sampling designs and perhaps stratification schemes are driven at least partially by the desire to estimate change.

5.1 Plot configuration

Selection of a plot configuration is based on multiple general principles, many of which are the same for boreal, temporal and tropical inventories, although some are different. Precise estimation of change is known to be more difficult than precise estimation of current conditions, particularly when the change is only for a small area. However, remeasuring the same plots on successive occasions can increase the precision of change estimates. In addition, the land area

of interest could be stratified for variance reduction purposes using a variable relating to the likelihood of change. Thus, the emphasis on estimation of change in tropical inventories argues in favour of a relatively large proportion of permanent plots which, in turn, argues in favour of marking or determining the locations of trees, so that they can be relocated for successive inventories. Although establishment and measurement of a temporary plot is less expensive than establishment and measurement of a permanent plot, establishment and measurement of different temporary plots on two occasions is not necessarily less expensive than establishment, measurement and re-measurement of a single permanent plot.

Although no strong consensus exists regarding plot shape, circular plots are often preferred because they require only single control points, the plot centres. Rectangular plots require four control points, one at each corner. In addition, for a given plot area, a circular plot has a smaller perimeter meaning that fewer decisions will be necessary as to whether particular trees are or are not on the plot. Also, determining coordinates for individual trees, which may be necessary for assessing their change, may be easier for circular plots which have only a single control point, than for rectangular plots which have four control points. However, if tree densities are exceptionally large, then long, narrow, rectangular plots may be a more feasible alternative.

For purposes of logistical efficiency, monitoring and inventory programmes typically configure plots in clusters. Because of expected access problems, configuring plots in clusters may be even more crucial for tropical programmes. Thus, individual plot size and the number of plots within clusters are subject to multiple important considerations, all of which are generally related to logistical, cost and precision considerations (Scott, 1993; Tomppo *et al.*, 2010a; 2011). First, plots should be small enough and few enough within clusters to allow a field crew to measure the entire cluster in a single day. The greatest proportion of the cost of measuring a plot in boreal and temporal forests is travel to and from the plot location; this proportion is likely to be even greater for tropical forests for which many regions are remote and nearly inaccessible. Thus, greater efficiency is achieved if field crews are not required to return to the same plot location on multiple days. Second, plot features such as radiuses for circular plots or lengths for rectangular plots must be measured on a horizontal plane, not along irregular terrain. Because measurement on a horizontal plane is more difficult for larger plots, particularly in hilly and mountainous terrain, smaller plots are again preferable. Third, establishment of permanent rather than temporary plots to facilitate estimation of change usually requires either marking or determining coordinates for individual trees. The latter approach is more difficult for large plots in dense tropical forests because more trees will be located between the tree of interest and control points. An argument in favour of larger plots for tropical inventories is that tropical forests are typically more diverse than boreal and temperate forests, implying that the total area inventoried at each sampling location should be greater to capture the greater diversity. However, this greater size could be achieved by increasing the number of small plots in the same plot cluster. This approach is cost efficient when the spatial correlations among observations of the variables of interest are large but decrease with increasing distance.

Greater sampling efficiency is also achieved by using small subplots for measurement of smaller diameter trees. For circular plots, the subplots are usually nested (i.e. they take the form of concentric circles all with the same centre). The particular sizes of the subplots and the diameter thresholds corresponding to the subplots should be based on the expected number of trees to be found on the subplots, the expected similarities of trees, and the travel time between subplots of the same plot or plots in the same cluster.

Finally, the remote and mostly inaccessible nature of many tropical forests means that inventories may have to rely on a combination of plot and remotely sensed data. Thus, remote sensing considerations may be necessary when selecting a plot configuration. As an example, a plot should be large enough to constitute an adequate sample of the trees on the ground element corresponding to the remotely sensed element (e.g. satellite image pixel, Lidar footprint) that contains the ground element centre. In addition, a desire to align different plots in the same cluster with different remotely sensed elements may require distances between plots to be at least as great as the dimensions of the remotely sensed elements.

5.2 Sampling design

Selection of a sampling design for a tropical forest inventory entails consideration of multiple principles. First, spatial balance is generally a preferred feature of sampling designs, which means that large geographic regions of the population do not remain unsampled. Spatial balance is often achieved by incorporating a systematic component into the sampling design. This may take the form of a network of perpendicular grid lines or a tessellation of the population into regular polygons. Spatially aligned designs establish plots at grid intersections or centres of polygons, whereas spatially unaligned designs establish plots at random locations within the rectangles formed by the grid lines or the regular polygons.

Remote sensing considerations may also be appropriate when selecting a sampling design. For example, tropical forests are often characterized as having relatively few days without cloud cover. Thus, cloud-free imagery for satellite-based sensors, such as Landsat or SPOT, may be difficult to obtain. Lidar data, which are currently acquired from airborne platforms and use laser techniques, are often proposed as an alternative. In addition, laser pulses penetrate forest canopies and produce useful information for estimating volume, biomass and the carbon content of trees. If plots are located at the intersections of perpendicular grids, acquisition of Lidar data from airborne platforms in strips is facilitated because straight flight lines can be used.

Finally, when constructing grid networks and tessellations, consideration should be given to use of equal area projections. If not, then plots located at greater distances from the equator will represent less population area than plots located closer to the equator. Although weighting schemes can be used with unequal area projections, they are often complex and bothersome.

As previously noted, the greatest proportion of the cost of measuring a plot is travel to and from the plot location. This proportion may be very large in tropical forests with remote and inaccessible regions (Tomppo *et al.*, 2011). Thus, cost efficiency dictates that plots be established in clusters rather than singly. Multiple approaches to cluster sampling are popular. One approach is to configure a plot as multiple subplots in a regular pattern and in close proximity to each other (McRoberts *et al.*, 2005). With this approach, the data for all subplots may be aggregated and attributed to the plot centre. A second approach is to establish plots in clusters configured as rectangles, half-rectangles or other geographic shapes (Tomppo, 2006). A third approach is two-stage cluster sampling. With this approach, primary sampling units such as polygons in the form of large rectangles are first randomly selected, and then multiple secondary sampling units in the form of plots are established within the selected polygons at randomly selected locations. When using cluster sampling, consideration should be given to the spatial correlation among observations for plots within the same cluster. If distances between pairs of plots are less than the range of spatial correlation, observations will tend to be similar and the sampling will tend to be less efficient.

5.3 Stratification

Stratified approaches to sampling are used for multiple reasons, but primarily to vary sampling intensities to accommodate selected criteria. For example, for an MRV that emphasizes geographic regions subject to human-induced carbon emissions, lesser sampling intensities may be acceptable for remote, inaccessible regions less likely to be developed or harvested. In addition, the cost associated with greater sampling intensities in remote regions may be prohibitive. Nevertheless, sampling, albeit with lesser intensities, must be conducted in these regions to achieve spatial balance.

Multiple principles also guide stratified approaches to sampling. First, strata with stable boundaries are generally preferable. Otherwise, changes to boundaries of strata with different sampling intensities lead to different sampling inclusion probabilities and complicate estimation. In addition, stratified estimation requires that a plot be assigned to one and only one stratum. If the stratum to which a plot is assigned changes between measurements, then difficulties arise as to the stratum to which a plot change observation should be assigned. Thus, strata defined by topography, climatic zones, biomes or political boundaries may be preferable to strata defined by forest attributes such as density or perhaps forest type.

Stratified sampling is most often implemented using one of three plot allocation schemes. With equal allocation, the same number of plots is allocated to all strata, regardless of strata sizes. This scheme is preferred if the objective is estimates for individual strata. With *optimal allocation*, sampling intensities selected for strata are based on optimization criteria, such as measurement costs, and/or within-stratum variation of observations of variables of interest, such as volume or biomass or their likely changes. Greater sampling intensities are selected for strata with greater variation and/or lesser measurement costs. With *proportional allocation*, sampling intensities selected for strata are proportional to strata sizes. Cochran (1977) provides a comprehensive discussion regarding alternative strategies. For tropical countries with large, remote and nearly inaccessible regions, some form of optimal allocation will usually be necessary to mitigate the excessive costs associated with sampling these regions. Proportional and optimal allocation can be easily implemented using sampling designs based on networks of perpendicular grid lines. With proportional allocation, plots or plot clusters are established at grid intersections without regard to the stratum associated with the grid intersection. With optimal allocation, sampling intensities can be increased or decreased for different strata by selection of grid intersections at which plots are established. For example, if the sampling intensity is to be reduced by a factor of four, plots can be established at the intersections of every second grid line only in each direction.

5.4 Case study – Tanzania

For a sampling design for Tanzania, Tomppo *et al.* (2010a) used double sampling for stratification and optimal allocation of plots to strata. The first-phase sample consisted of an office assessment of a dense grid of field plots for assignment to volume and cost classes. Based on these assessments, strata were constructed using predicted cluster-level average volume of growing stock and estimated cost to measure a plot cluster. Volume classes were based on volume predictions using satellite imagery, observations for ground plots outside Tanzania, and robust models whose predictions were calibrated using areal volume estimates for Tanzania. Neyman allocation (Cochran, 1977) was used to select boundaries for the volume classes, so as to maximize the precision of the overall volume estimate assuming a fixed sample size. Cost classes were based on GIS analyses and local expert opinion of the number of days (one, two, more than two) necessary to measure a plot cluster.

Selection of the class intervals, which affects the gain that can be achieved with stratification, requires greater investigation. The second-phase sample consists of field measurement of plots where within-strata sampling intensities were selected using optimal allocation (Cochran, 1977). With optimal allocation, sampling intensities are proportional to the quantity $\sigma_h / \sqrt{c_h}$ where σ_h is the within-stratum standard deviation for observations of the variable of interest (mean growing stock volume) and c_h is the average cost in terms of measurement time for a plot cluster in stratum *h*. More details concerning the sampling design can be found in Tomppo *et al.* (2010a).

In the tropics, use of available vegetation maps to delineate land into forest and non-forest is sometimes appealing. However, if plot clusters are not established on delineated non-forest land in the same manner as on delineated forest land, map errors could contribute to bias, as forest land erroneously delineated as non-forest land will not be sampled. However, allocating lesser sampling intensities to these lands can decrease the costs associated with sampling-delineated non-forest land. In addition, field measurement of plot clusters entirely outside forest and without growing stock can often be avoided by assessing such clusters with land-use information obtained from other reliable sources, such as those proposed for Brazil (Tomppo, 2009).

The lack of transportation routes, other than rivers, presents a special challenge for tropical forest inventories, such as in the Amazonian Biome. For example, roads may be available only a part of the year (approximately six months in the case of the Amazonian Biome). In addition, some forests may be designated for nature conservation purposes or for the sole use of indigenous peoples. Stratification based on relevant variables such as the likelihood of changes and measurement costs promote both cost efficiency and adherence to sound statistical inventory principles.

6. Summary

Construction of an appropriate sampling design for an NFA, NFI or MRV is a crucial step if estimates are to be sufficiently precise and scientifically defensible. One of the first steps in this process is to define the target population and select a sampling frame. The recommended option is an infinite population sampling frame in which observations and measurements of a field plot support area are attributed to the point at the field plot centre. Because inventories are often expected to produce estimates of change, it is recommended that the sampling design include at least some permanent plots. The next step is to distribute the field plots throughout the population to be sampled. This chapter has presented information on and discussed several popular sampling designs: simple random sampling, stratified sampling, systematic sampling and cluster sampling. If the sampling design includes a systematic component, caution is recommended when using rectangular grids for target populations with large north-south components. Although the selection of the particular sampling design depends on a variety of considerations, if stratified sampling is not used, consideration should be given to post-sampling stratification and stratified estimation. Finally, additional information on these and more complex sampling design issues is available in the reference material.

Self-study exercises

1. Describe the differences, advantages and disadvantages of simple random, systematic, stratified and cluster sampling designs.
2. Explain why a stratified sampling design may be superior to a simple random or systematic sampling design. Describe ancillary data that may be useful for constructing strata.
3. What role does spatial correlation among observations or measurements of forest attributes play in the selection

of a sampling design and estimation of population variances?
4. Describe the criteria and information necessary to determine an appropriate sample size.
5. Identify sampling issues and constraints unique to inventories in tropical forests.

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Observations and measurements

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THIS CHAPTER DISCUSSES THE FOLLOWING POINTS:

- Methods for collecting observations at different sampling locations selected based on a given sample design.
- General aspects of different observation units, such as points, lines and areal plots.
- The different types of variables typically assessed in forest inventories.

Abstract

Observations and measurements are the basis for all data analysis and estimations in forest assessments. This chapter is concerned with the *response design* of forest assessments, sometimes also termed *observation design*, and covers the following questions: (i) What types of variables are typically assessed in national forest assessments? (ii) How are observations and measurements made on population elements selected from the population by the sample design? and (c) What can be done in forest assessments to achieve high-quality data.

Observations and measurements in NFAs are typically gathered in the field (either on field plots or through interviews) or via remotely sensed data. The decision as to which variables to observe in a particular NFA is relatively simple (though in practice sometimes not so easy) – the NFA must focus on those variables required to generate the target information. All variables need to be defined in an unambiguous manner and the measurement procedure itself must be defined in detail. There needs to be a clearly defined measurement protocol (often referred to as a field manual) for the successful implementation of the inventory in the field. The choice and organization of appropriate methods, instruments and tools influence the reliability and quality of the measurements. It is important to train field crews before field inventory practice, and supervise and independently cross-check field work, measurement devices (calibration) and the data delivered.

1. Introduction

The design components of a sample-based inventory can be subdivided into: (i) sample design, (ii) response design and (iii) estimation design, following a logical and also a temporal order. This chapter is concerned with the response design, sometimes also termed the observation design, and examines

how observations and measurements made on population elements are selected from the population by the sample design. Following this process, estimators are applied to the set of observed values, eventually producing estimations that constitute the results of the sampling study (estimation design).

Measurements and observations for NFAs are drawn from several different sources: maps, aerial photographs, satellite imagery and the field. Increasingly, Lidar is emerging as a source of remotely sensed data competitive with satellite imagery. While this chapter focuses on measurements in the field, the general observations on data quality and measurement strategies also hold for other forms of measurement.

2. Variables typically assessed in NFAs

2.1 Types of variable

Observations produce values for variables and are made on defined observation units. The term *attribute* is frequently used in the same sense as *variable*, where the term "attribute" refers more to the characteristic of the object, and "variable" has a statistical connotation defining the characteristics as random variables that take on observable values.

For the purpose of NFAs variables may be classified according to different criteria, including:

- *Classes of variables in a statistical sense* (depending on the scale on which they are observed). Here, "measurements" may yield a metric value (for metric variables such as distance, diameter or height) or a classification into one out of a set of two or more categories (for categorical variables such as species, forest type and soil type).
- *A distinction between directly observed and derived variables*. Some variables are directly measured/observed, such as diameter at breast height (dbh) or tree species, and some are derived/modelled, such as volume and biomass, and most observations of change (see chapter on *Modelling for Estimation and Monitoring p. 111*).
- *A distinction between status and change variables*. The majority of measurements give a *status* value for a given attribute. Only a few *change* attributes can be measured directly at one point in time. Typical examples include increment borings, where the change (increment) of dbh over a certain period can be measured directly, and the measurement of length of terminal shoots of coniferous trees. The estimation of changes for other variables (e.g. carbon stocks) is therefore based on measurements taken at two points in time.

The number and range of attributes typically covered in an NFS is wide. Traditionally, biophysical variables are observed, but there is a tendency to complement the data on the biophysical resource with stakeholder-oriented data on forest use. Tropical inventories also increasingly assess sociological and local economic variables for areas in the vicinity of plots. For example, a homeowner living close to a plot may be interviewed for purposes of assessing the degree to which indigenous populations use the forest. In addition, extension of the scope and goal of forest inventories both towards information provision for criteria and indicator (C&I) processes, and multiresource inventories/landscape inventories, leads to an extension of the types and number of variables included. The number of attributes observed on each plot can be as high as over 250 and, in most cases, is not less than about 100. It includes concept areas such as: "land use, forest area and forest type area", "growing stock", "carbon balance", "wood production", "non-wood forest products", "biological diversity in production forests", "soil erosion" and "water conservation in forests".[1]

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1 For more information see: www.pefc.org/ramme2.htm

2.2 Typically employed data sources

As NFAs are complex and usually expensive undertakings, it is important to make efficient use of the various sources of information. Fieldwork (i.e. sample-based observations from field plots and interviews) and analysis of *remote sensing data* constitute the main sources of up-to-date data and information.

A multitude of other sources of information are used in the planning, implementation and analysis of an NFA. These include maps, previous inventory reports and documents, research studies and expert knowledge. However, these are rarely used to retrieve data for analysis.

Photographs of plots and their surroundings provide additional possibilities to document the current situation in a comprehensive manner, and allow changes to be described qualitatively at a later point in time. However, such methods are not applied frequently, as they require efficient data and image management, and standard analysis procedures are often unavailable.

2.3 Which variables should be included in an NFA?

The decision concerning which variables to observe in a particular NFA is strategic. The assessment must focus on those variables required to generate the target information. In many forest inventories and NFAs more variables are observed than are eventually analysed and reported. While there is a "general documentation character" to all forest inventories, and such data can be helpful for subsequent and unforeseen information demands, it can also be a waste of resources.

It is advisable to mainly include those variables for which a direct use is known and on which the inventory will report directly (e.g. "forest type"). Variables used as an input for models should also be included. For example, NFAs do not usually report on "tree height", but it is used as input for various derived variables such as "volume/biomass/carbon" and "forest structure".

Ideally, analysis methods for all variables should be known *a priori*. It is useful to simulate the analysis before starting data collection, as this helps to identify additional variables for inclusion and can determine which variables are less useful and should be excluded.

It is important to emphasize that staff (field crews and image interpreters) must be able to make measurements/observations with reasonable effort. Furthermore, they should be able to acquire the respective knowledge in training activities with reasonable effort. For example, field observations of specific soil and site attributes will probably be limited to a few variables, unless a soil expert accompanies the field crew. The same holds for more comprehensive inventories of lower plants, specific non-wood forest products or wildlife. It is probably overambitious to expect field crews to be capable of identifying all tree species in a moist tropical forest, unless the team includes an expert dendrologist, which is likely to make the exercise more costly.

2.4 Defining the variables: the measurement protocol

To guarantee overall interpretable results, the variables need to be defined in a comprehensive manner. The inventory staff dealing with measurements and data must therefore have access to clear and understandable definitions. These definitions are usually written in an inventory manual. Many such manuals exist worldwide and can be adapted to create a new inventory manual.

All variables need to be defined *technically* in an unambiguous manner. The *measurement procedure* must also be defined in detail. A definition that lacks an indication of how to carry out the measurement is incomplete, and may lead unwittingly to results that are inconsistent. Typical examples include the variables *dbh* and *forest*.

For the variable "dbh" a complete definition

comprises the following:

- The height at which the dbh is to be measured (1.3 m)
- How to proceed in cases where 1.3 m is an impossible height to measure (usually presented as a set of drawings)
- The measurement unit to be taken and the scale (e.g. centimetre, to the first decimal)
- The measurement device to be used and what to observe while using it.

For the variable "forest", quantitative (e.g. minimum crown cover, minimum width, minimum height, minimum area of a forest patch, etc.) and qualitative (e.g. definition of tree, vegetation types, etc.) criteria are usually defined. In a small number of cases, a definition is also needed for a procedure to measure "crown cover" or "stand width" in a concrete case.

For categorical variables, each occurring category (class) needs to be considered, either as a separate category, or aggregated with others into one class. For some variables it is recommended to use the class "others" for unforeseen cases. The class descriptions should allow field crews to make rapid and clear decisions, and the classes themselves should be meaningful for the analysis. Regarding measurement procedures, variable thresholds and measurement protocols are increasingly considered in the larger context of the ability to report in a manner comparable/compatible with international processes (Tomppo *et al.*, 2010).

3. Measurements

3.1 Basic measurements

The measurements carried out in forest inventories are usually of the following types:

- Measurement of distance/length
- Measurement of angles
- Measurement of areas (using maps or remotely sensed data)
- Measurement of position (satellite navigation)
- "Measurement" of condition class (i.e. classification – assigning an object to a defined set of condition classes).

Measurement of distance/length

Length measurements are made for individual tree characteristics (diameter and height also correspond to distance/length), plot establishment (e.g. the radius of a circular plot) and when navigating to the chosen plot location. Distance/length measurements can be made directly or indirectly. *Direct* measurements of tree heights can reasonably only be done with small trees, usually regeneration trees. Direct measurement involves placing a ruler or a stick with metric subdivision next to the tree and recording the height. *Indirect* linear measurement is accomplished by using techniques such as geometry and trigonometry to calculate the length. Many measurement techniques and devices are available, which vary widely in cost and accuracy.

Different options are available to measure distance, including estimation by "calibrated" pace (pacing), measurement by tape (horizontal measurement) or measurement by mechanical-optical devices (Blume-Leiss, Suunto). Higher speed and accuracy (at higher cost) are obtained with instruments that use laser or ultrasonic technology (e.g. Vertex). These calculate distance based on interferometry of wavelength or the time that a sound impulse takes to travel the distance to the target object.

The most commonly used instruments for measuring dbh are callipers and diameter tape. Tree height is measured indirectly through a simple trigonometric or geometric approach using mechanical-optical or electronic devices, such as the Spiegel Relascope, or hipsometers (e.g. Blume-Leiss, Haga, Suunto, Silva, Vertex, etc.).

In all cases, length measurement needs to follow clear definitions. Distances measured in the field are usually meant to be horizontal distances and need to be corrected in sloped terrain. Tree height is the vertical distance

between the highest and lowest point of the tree, and not necessarily the length of the oblique/curved stem.

Measurement of angles

Slope angle and bearing are basic components of various measurements. Slope angle measurement is necessary to measure tree height, to determine a factor for slope correction of plot area, and to reduce slope distances to horizontal distances.

Measurement of areas (using maps or remotely sensed data)

Direct measurements (as opposed to sample-based estimations) of areas are carried out only with maps and remotely sensed data, usually after having digitized the corresponding polygons. Measurement of areas is rarely carried out in the field, although this can be accomplished with the assistance of GPS or electronic distance meters in combination with a digital compass. If, for example, the plot area needs to be determined, as it falls outside the present condition class, then the normal approach would be to avoid direct measurement and instead use distance measurements to calculate the area.

Measurement of position (satellite navigation)

Satellite navigation uses distance measurements via a set of satellites to determine three-dimensional positions. Three basic functions are important for NFAs: (i) *navigation*, or "finding the way to the sample plot in the field"; (ii) *position*, or "determining the position of sample points or other reference points in the field"; and (iii) *tracking*, or "monitoring the movement of people". The latter can be used to document the access path to a plot, thereby helping to ensure that field crews reached the correct target sample plot location.

Regarding GPS receivers, the highest-grade receivers affordable should be considered. Plot locations are increasingly registered via remotely sensed data such as satellite imagery pixels or Lidar pulses. Higher-grade GPS receivers greatly facilitate this process. McRoberts (2010) showed that approximately half of inventory plots registered via GPS receivers with an accuracy level of 10-20 m are associated with incorrect Landsat pixels.

"Measurement" of condition class (classification)

For categorical variables, measurement concerns the assignment of a response to one of a set of defined classes. Here, the complete set of possible "values" (classes) needs to be defined. Typical examples include the variables "forest type" or "tree species".

Subjective estimations of values/guesses

Not all measurements follow objectively reproducible observation procedures. Sometimes, guesses are a quick method for data provision. However, for obvious reasons their use should be restricted to those variables where more objective and reproducible data acquisition techniques are not feasible.

Measurements of some NFA relevant variables

The concrete set of variables to be covered by a specific NFA depends on the specific set of objectives. The variables can be grouped into major subject areas. As an example, a comprehensive comparative study of European National Forest Inventory Systems (European Commission, 1996) used the following grouping of variables:

- Geographic and topographic variables
- Ownership variables
- Variables on wood production
- Variables of site and soil
- Variables concerning forest structure
- Variables concerning regeneration
- Variables concerning forest condition
- Variables concerning accessibility and harvesting
- Variables describing forest ecosystems
- Variables concerning non-wood forest products.

4. Observation units and their characteristics

Once the sample design is complete, objects are selected for observation. Each selected object constitutes *one* independent observation for estimations of the mean, variance and variance of the mean (Cochran, 1977; Gregoire and Valentine, 2008).

The "objects" selected for observation in NFAs usually comprise one of the following types:

- Individual elements (e.g. tree)

In NFAs we usually employ an areal sample frame, selecting the position of our observation units on a map. The observation units can be characterized by its dimensionality:

- points: dimensionless observation units,
- lines: one-dimensional observation units, and
- areas, fixed or variable: two-dimensional observation units.

Each object has its specific characteristics discussed in the following.

4.1 Individual elements

The selection of individual elements as observation units is not a major issue in the context of NFAs. This is mainly done when not all tree variables can be observed on all individual trees within a plot (e.g. tree height). Subsampling of individual trees can be performed to obtain these measurements. In these cases, a common way to determine which trees to measure is to use a non-sampling approach (e.g. the five trees closest to the plot centre or a certain number per main tree species will be measured for height).

The issue of selection and observation of individual elements can also arise during interviews. Here, individual "elements" are selected for observation (e.g. forest owners, forest users, etc.).

4.2 Points (dimensionless observation units)

Sample points are commonly used to estimate the area of condition classes in remote sensing imagery. This is also the case in the field where the centre of a plot is a sample point in which values of categorical variables are observed. These may be values of binary variables (e.g. forest/non-forest, burned/not-burned) or of a categorical variable with more than two classes (e.g. forest type, soil type, ownership).

4.3 Lines (one-dimensional observation units)

Lines are one-dimensional observation units without width. Narrow strips, sometimes erroneously also referred to as lines, do have a width and full under the "area" type (see section 4.4, p. 47). Line sampling can be applied with remotely sensed data, as well as in field sampling. A common application in NFAs relates to the use of cluster plots, where the connecting line between the subplots is used as an observation unit.

A limited set of observations can be made regarding lines:

- Lines can be used as a tool to select individual elements from a population. For example, once a sample line is laid, measurements can be taken where it intersects with understory shrubs. However, this application is not a common in the case of NFAs.
- The number of intersections of a sample line with one-dimensional features in the forest or landscape allows the total length of these features to be estimated. This is based on a technique called "line intersect sampling".
- The proportion of sample line length that passes through a particular condition class allows for estimation of areas and area proportions. This is based on a technique called "line intercept sampling".

4.4 Fixed or variable areas (two-dimensional observation units)

Sample plots are probably the most important observation units in forest inventories. A variety of plot types are used for this purpose. All plot types include a set of trees for one single selection step of the sampling procedure. Plot-related variables (e.g. forest type, topographic variables, soil variables) and tree variables are usually observable on a plot.

It should be clearly understood that, for plot and tree variables, the entire plot is the observation unit, and each plot delivers one independent observation for estimation (i.e. the plot mean or the plot total).

Fixed area plots

Fixed area plots are probably the most frequently applied and for many situations constitute the most practical, efficient and easiest to process plot design option. As soon as the plot position is located, plot and tree-related measurements are made. Tree measurements are taken for all trees included in the sample, based on the stipulated plot shape and size, while plot measurements are taken at defined locations within the plot area. The most common shapes are circular, rectangular and square plots. There is no standard plot size. In temperate and boreal regions, sizes of 500 m² and 1 000 m² are common; in the tropics, larger area strip plots are usually employed, for example, 20 m x 250 m.

Nested plots, regeneration plots

It is inefficient to work with a single plot area for all tree dimensions. Natural forests, in particular, often have very many small trees and only a few bigger trees on a given area. Therefore, different sample areas are used for different tree dimension classes. Plots are also of different sizes. While the whole plot is referred to as such, smaller plots are termed subplots, microplots or regeneration plots (when used to observe regeneration). For practical reasons, these subplots are usually contained within the plot area, and so are referred to as nested plots. Nested plots can be designed for any plot shape and may also combine different plot shapes. In the tropics, for practical reasons, subplots for larger trees frequently take the form of strip plots, while smaller circular plots are used to observe regeneration.

There is some discussion as to whether subplots, for example, for regeneration measurement, may be placed completely or partly outside the "main" plot. There is no objection to this from a methodological point of view. However, in rare cases this subplot section might fall under another forest type, which can complicate data recording.

It is not a good idea to place regeneration plots in the centre of a circular plot or directly on the central track of a strip plot, as there is a strong chance that the regeneration plants will be disturbed or otherwise damaged by the field crew.

Variable area plots for horizontal point sampling

The concept of different plot sizes for different dbh classes can be extended to allow every dbh a specific-size circular plot. The resulting plot design is known under a variety of names – variable area plots, relascope plots or Bitterlich plots after the Austrian inventor of the method, Walter Bitterlich. A sample point is selected and all trees that appear wider than a defined angle (from the perspective of that sample point) are included in the sample. This means that the strictly size-proportional selection of sample trees is made indirectly by establishing that particular view angle.

A simple *count* of the included trees produces a design-unbiased estimation of basal area per hectare. If the focus is the number of trees per hectare, the dbh of all sample trees must also be measured. It is important to note that this design is very efficient for estimation of basal area, while it is less recommendable if estimates on density (number of trees per hectare) is targeted.

Different measurement devices have been developed to carry out relascope samples. A simple stick with a small plate at the end works as well as the thumb on the extended arm. In some regions, wedge prisms are used. The relascope offers many more additional functions.

Some variations on relascope plots have been developed (e.g. strip relascope sampling, vertical point sampling), but have little practical relevance for NFAs at present.

Point-to-object, object-to-object plots

Mainly known from ecological applications and lesser from NFAs are observation units in which not all the trees on a predefined plot area are included, but a fixed number of k closest trees to each sampling location. The number of trees per observation unit is then constant, but the "plot size" varies depending on density. A model-based approximation of a reference area for a particular observation might be defined by the distance to the n-th tree defining the radius of a virtual circular plot. This is a very practical and rapid method in the field; however, unbiased estimations are only possible if the spatial arrangement of trees is random. As this is usually not the case in forests, systematic errors are to be expected, particularly if the spatial distribution of trees is clustered.

Boundary trees, border plots and slope correction

Boundary trees. In the case of fixed area plots, it may not be immediately obvious whether a tree is actually in the plot or not. Verification can be time consuming, particularly as the aim is to minimize the number of trees to be controlled. Circular plots are optimal in this sense, as the circle has a minimum perimeter for a given area, and therefore a minimum number of boundary trees. Rectangular plots are much less optimal, as their perimeters are much longer for the same area.

In this context, a clear definition must explain which trees are to be included and excluded. In most cases, the virtual centre axis of the stem defines its position: if it falls within the plot area, then the tree is included. The same is true for highly oblique trees, even if the projection of its dbh lies outside the plot boundary. Conversely, an oblique tree that hangs over the plot is not included if its centre axis lies outside the plot area.

Border plots. Border plots partly overlap the boundary of different target condition classes (e.g. forest type). These plots are an issue of concern, especially when the study refers exclusively to the target condition class (e.g. forest). If the inventory extends to all vegetation and land-use classes (landscape type of tree inventory), border plots will occur more sparsely and only at the edge of the sample frame.

Sample plots are established if their defined reference point (the centre for circular or square plots or the starting point for rectangular plots) falls into the target condition class (e.g. forest). If a sample point falls outside, a plot will not be established, although part of it might be in forest.

Several options are presented in the literature for dealing with border plots. The mirage method is accepted to be practical and unbiased: the section of the plot that falls outside the forest is mirrored back into the forest and trees in this mirrored-back section are included in the sample twice.

Some have discussed the option of leaving out border plots or shifting them until they lie completely within the forest. This approach will produce systematic errors of unknown magnitude and should not be applied.

Slope correction. Where a plot is defined as covering 1 000 m^2, this area refers to the map plane, as is the case for all area values used in forestry. In the case of slopes, it is important to use horizontal distances when measuring distance. The field crew can either hold the distance tape strictly horizontal (or use an instrument that measures horizontal distance automatically), or employ a "slope correction"

which guarantees that the area measured in the field will give the defined plot area when projected to the horizontal. The larger the actual area measured on the slope, the bigger the slope angle. In the case of circular plots, the procedure is to calculate the area of the ellipse by projecting the circle from the map plane onto the slope. The radius of the area-equivalent circle is then determined and used for the field plot.

Slope corrections need to be applied to all types of lines and area observation units. Some measurement devices automatically correct for slopes, for example, the relascope for variable plot sampling. Slope correction factors should be included in every forest inventory field manual.

5. Optimization of plot design

5.1 Fixed area plots

The approach used for sample design optimization is also used for plot design. Optimization is usually undertaken for one principal variable, often growing stock. In the case of NFAs, however, many variables are observed and are considered to be of importance. In such instances it is often advisable to make a formal optimization along a key variable (usually volume) and make a pragmatic decision taking into account general experiences from other NFAs.

The aim of the sampling exercise is to achieve the highest possible precision for a given cost (or the lowest cost for a defined level of precision). The response design contributes to this target by attempting to capture as much information as possible in each single observation unit.

It is obvious that, for a given sample size, larger plots yield more precise results, as more information is collected (at a higher price). However, for plots of a fixed size (e.g. 1 000 m^2) it is possible to vary the plot shape, which may also have a significant effect on precision.

The overall objective of plot design is to maximize variability, notwithstanding practical and budget limitations, by encompassing as many different conditions as possible. (This is different from designed experiments, where the conditions in an experimental plot should be as homogeneous as possible). High variability within a plot minimizes the differences between plot values of a sample, which in turn leads to smaller standard error.

With respect to plot shape, given the same plot area, the following statistical conclusions can be made:

- Elongated rectangular plots (strip plots) may be preferable to compact shapes, such as circles or squares.
- Cluster plots with spatially disjoint subplots are better than single plots.

However, the gain in statistical efficiency relates exclusively to the structure of the forest to be sampled (i.e. with the spatial autocorrelation of the variables of interest).

Of course, certain practical aspects are of equivalent or even greater importance (see chapter on *Organization and implementation*, p. 13). In cluster plots the field crews spend much time walking, while in strip plots the number of boundary trees to be carefully checked is much higher than in circular plots of the same area (because of the minimized perimeter). In the case of circular plots, field implementation is more straightforward, as these are defined by locating a single centre point.

Visibility in the stands is also an important issue. Strip plots are preferred for poor visibility, as they allow observations to be made at relatively short distances from both sides of the central track. Circle plots are preferred for good visibility, as they enable faster measurement progress.

A valid (though uncommon) approach is to combine, in the same survey, plots of the same area but different shapes. It should be stressed, however, that the plot shape should not be determined only in the field, and should make adjustments, for example, for terrain conditions.

Empirical evidence has found that about 15–20 trees per plot is a good value for plot size. Having an idea of diameter distribution (e.g. from earlier inventories) can help to determine sizes of plots and subplots for different dbh classes.

Cluster plot optimization

Cluster plots are employed in most NFAs, mainly for practical reasons. Transport is commonly expensive, so it is important to capture as much information as possible at a specific location as possible (Tomppo *et al.*, 2010). Single large plots are highly inefficient, so the plot area is subdivided, and cluster plots of spatially disjointed subplots are established (sometimes also called tracts). The entire cluster of plots, arranged in a fixed geometric configuration, is the observation unit, yielding one single observation for estimation (Köhl *et al.*, 2006). The spatially disjointed areas constituting the cluster are subplots of this cluster plot. It is important to note that the whole set of subplots in a fixed configuration is selected by only one sample location (one selected sample point based on the underlying sample design). As in a probability sample, the sample size refers to the number of independently selected elements; the subplots cannot therefore be treated as individual observations. In consequence, the whole cluster delivers only one observation.

Optimizing a cluster plot design involves considering a number of criteria and balancing practical and statistical aspects. Decisions need to be taken regarding the following points and may require trade-offs:

- Geometric spatial configuration of subplots: subplots may be arranged in a number of ways including a square tract, a half square (L-shape), on a line, triangle, cross, etc.
- Spatial distance between subplots: the larger the distance between the subplots, the statistically more efficient the plot design; however, more time is used walking between subplots.
- Type of subplots and size of subplots: the same considerations hold as those made for single plots.

As a cluster plot typically has a much larger spatial extent, it is more likely that such a plot will intersect the boundary of the sample frame.

6. Temporal versus permanent observations

Observation units, viz. sample plots, are either measured once in an inventory (temporary plots) or repeatedly in subsequent inventories (permanent plots). In the latter case, exactly the same plot is being visited again. Permanent plots are established to allow for efficient estimation of *changes*.

Plots need to be registered and marked so that they can be found at a later date (see chapter on *Organization and implementation*, p. 13). This is usually done with the use of visible or invisible markers in the field, a sketch map, distance and bearing measurements to reference objects, and/or by GPS measurements. In order to generate "time series" of tree measurements, the individual trees also need to be recorded in a manner that allows later measurements to be attributed to exactly the same tree. Tree markers, such as numbered aluminium tags, can be used for this purpose (although these can be easily removed). Alternatively, the tree position can be recorded using a reference system (e.g. distance and bearing to plot centre of circular plots; length, side and perpendicular distance from the central track of a strip plot).

Once the tree positions are recorded, the next step is to spatially record/map other features (e.g. stand boundaries, dead wood, etc.) so as to produce a *mapped plot design*.

The creation of "permanent" plots requires a thorough and consistent approach to documentation, data management and project management.

7. Concluding remarks

7.1 Data quality

Observations and measurements are the basis for all data analysis and estimations in forest assessments. It is therefore imperative to guarantee a high level of data quality. Data quality means that:

- Each single measurement is made with care and accuracy.
- All measurements of a particular attribute follow the same specifications (in terms of definition and measurement procedure).

Measurement errors are usually not considered when accounting for errors in forest inventories. For the statistical analysis it is commonly assumed that all measurements are taken without error. Similarly, the uncertainty associated with model predictions of individual tree volume and/or biomass is also usually ignored (see the Chapter on Modelling for Estimation and Monitoring). That means that the error figures that statistical estimations provide must generally be taken as nominal errors, being a lower bound of real measurement errors. However, studies of error budgets for a large area forest inventory (Gertner *et al.*, 1992) suggest that the standard error originating from the sample design is, in fact, the error component with the greatest relative relevance.

The following points can help forest assessments achieve good data quality:

- Assessment and measurement protocols: ensure complete and clear documentation and descriptions.
- Staff: undertake careful selection and training of field crews.
- Supervision: ensure oversight and control of fieldwork, measurement devices (calibration) and data delivered.
- Verification: undertake careful checks and calibration of measurement devices.
- Plausibility: undertake final checks when data are entered into the database.

7.2 Non-response

Non-response is a sampling "feature" that forms a default point of discussion in the social sciences, where data collection is based mainly on interviews. In this context, observations cannot be taken for a subset of sampled "elements" because the persons do not respond.

Similar situations can occur in forest inventories. For example, sample plot locations may be inaccessible, or clouds and shadow may preclude observations for certain sections of satellite imagery. It is important to treat those cases correctly as non-responses and possibly apply imputation techniques. It is not good practice to shift those plots, for example, to more easily accessible areas, or to simply ignore them (Patterson *et al.*, 2011).

7.3 Practical issues

It is important to keep in mind that fieldwork to gather data is often physically extremely demanding. Data quality depends heavily on the motivation of the field crews. It is, therefore, important to ensure optimal working conditions for all involved (including travelling and lodging) to the extent possible.

Self-study exercises

1. Explain why a major statistical planning criterion for the choice of a plot design is to capture as much of the given variability of the target variable as possible inside each observation.
2. List some target variables that could be estimated based on one-dimensional line elements as observation units.
3. Explain the rationale of a nested plot design, in which trees of different diameter classes are included in subplots of different area size (smaller trees in small plots, large trees in large plots).
4. If an NFA is being carried out for the first time, what sources of information might form a suitable basis for a decision on plot design options?
5. A decision-maker contests the reliability

of the results in an inventory report on the grounds that only 0.001 percent of the country's forest area was observed in the field. How can the reliability of the results be defended?

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Data collection through interviews

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THIS CHAPTER DISCUSSES THE FOLLOWING POINTS:

- Approaches for collecting data on forest use through personal interviews.
- Data quality factors, including: (i) content of questions; (ii) sampling strategies; (iii) interview methods; and (iv) data quality verification systems.
- Practical tests for managers to compare and assess the viability and reliability of alternative approaches for collecting data through interviews.

Abstract

National forest assessments (NFA) collect data through field interviews with forest users. However, many individuals involved in forest inventories typically have not received training on conducting personal interviews. The purpose of this chapter is to offer practical advice on this topic. The overall quality of data derived from the NFA interview component depends on how four key questions: What questions should the NFA ask? Who should be interviewed? How should the interview be conducted? What is the best way to verify data quality?

The chapter also discusses the concepts of validity and reliability, which are central to quality assessment of NFA interview results, and presents several practical tests to evaluate these criteria. The suggested approach to quality control aims to simplify and strengthen interview results, at minimal cost in terms of time and resources. The benefits of a robust quality control system include improved credibility of NFA results and higher likelihood of the NFA affecting future policy decisions. An NFA that is effective in capturing the perceptions of local forest users with regard to their forest use, will help to identify factors causing observed changes in forest conditions, and can also show how these changes are likely to affect different groups of people within a given country.

1. Introduction

Over the last three decades, practically all members of the international community have reformed their national laws and policies in accordance with the principles of international environmental treaties, such as the Convention on Biological Diversity (1992) the Convention to Combat Desertification (1992) and the United Nations Framework Convention on Climate Change (1992). All FAO member governments now officially promote sustainable use of their tree and forest resources. Nevertheless, most

governments have very limited information about the effects of their recent changes in public policy concerning forestry and rural development in general. Policy actors are now demanding answers to a number of important questions on policy objectives: In what ways have forestry activities helped to achieve food security and alleviate rural poverty? Have there been any substantial changes in forest use patterns and resource conditions as a result of the new policies? Can observed changes in deforestation rates be attributed to specific policy interventions?

These questions have taken on additional importance with the introduction of the new global initiative REDD+ (Reduced emissions from deforestation and forest degradation plus the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries), which is designed to induce developing country governments to promote forest protection. To find answers to these questions, and certainly to participate in the REDD+ transactions, policy-makers need monitoring programmes that go beyond conventional forest inventories and measure characteristics of resource users and their use of the resource.

The effects of public policy on forest conditions cannot be explained without a thorough understanding of how forest-users' decisions reflect public policies (Gibson, McKean and Ostrom, 2000). Hence, information about forest users provides a link between forestry policies and observable outcomes on the landscape (Andersson, 2002). The challenge, then, is to ensure that the information gathered about forest use and forest users is both valid and reliable.

The rationale for conducting field interviews as part of an NFA is quite straightforward: they have the potential to increase the policy relevance of the inventory results. The inclusion of data on the human use of forests and related land use, if done properly, allows national forest policy analysts and decision-makers to develop knowledge of the human factors that affect the variability of forest conditions in a country, something that traditional forest inventories have not been able to deliver. With such knowledge at hand, it is possible to monitor certain key aspects of forest governance performance and potentially provide evidence-based indications of how effective national policy objectives are achieved. If such monitoring systems are functional, and policy-makers and analysts are interested in learning from the results they produce, this information can be of significant value for actors seeking to improve the effectiveness of policy interventions. Hence, NFA interviews aim to produce two specific outputs: (i) monitoring of forest governance performance; and (ii) identification and monitoring of human drivers of forest change.

To achieve these outputs, however, valid and reliable field methods are needed to produce high-quality data. This chapter examines the question of how to organize an NFA interview component to produce data of the highest possible quality.

2. Background

The data that NAFORMA personnel collect in the field come from two different measurement components. For biophysical data, direct measurements and observations are used. For data on forest use and users, field crews conduct interviews with a sample of local households and key informants in the vicinity of the biophysical sample plots.

In the NFA interview component, field personnel document the goods and services derived from the sampled site; identify their relative importance for different local people; ascertain who has the right to harvest what products, and when and how they are harvested; identify the end use and purposes of these products; and record whether users perceive demand and supply to be stable, increasing or decreasing.

To capture this information, field personnel conduct interviews with selected local forest users who either extract resources

from the site or have information about the products extracted. Depending on the availability of resources and the specific goals of the interview component, the NFA management may decide to conduct a variety of different types of interviews, targeting different populations of interest. Based on previous experiences in countries that have incorporated field interviews into their NFA, it is recommended that interviewers conduct two types of interviews at each field site location: interviews with sampled households (probability sample) and interviews with local key informants (non-probability sample).

Each type of interview uses a set of structured questionnaires (see Appendix 1, p.66).The questions in each questionnaire should reflect the priority needs of stakeholders, as expressed during the needs assessment, which should take place during the planning phase of the NFA.

The purpose of this chapter is to help the NFA organize the interview components, such that the data gathered through interviews are accurate and useful for decision-making. The chapter is organized around four central questions. The way in which the NFA teams address these questions will ultimately determine the quality of the data gathered. These four questions are:

- What questions should the NFA ask?
- Who should be interviewed?
- How should the interview be conducted?
- What is the best way to verify data quality?

3. What questions should the NFA ask?

3.1 Data content and format issues

The quality of interview data will not only be determined by the methods used for data collection, processing and analysis, but also by a more fundamental choice made by the NFA managers: the selection of variables of interest. The most important source for deciding which variables should be measured in the NFA interview component is the needs assessment conducted during the planning phase of the NFA. The needs assessment involves a series of meetings with stakeholders, at which a wide variety of interested actors are invited to express their opinions and suggestions regarding the proposed content and methods of conducting field interviews.

The needs assessment should clarify and prioritize the most urgent information and knowledge gaps with regards to forestry planning and decision-making at the national level. As such, the assessment should address the following questions:

- What current “hot topics” relating to forest use and forest users could the NFA interview component shed new light on?
- What current knowledge gaps prevent national forest policy from increasing its cost-effectiveness?
- Which types of analytical products would different stakeholders find most useful? What media and formats would be appropriate for such products?

Systematic documentation of these information needs and demands can help the NFA management make more informed decisions on a wide range of issues. Possible issues include the focus of the interview (which questions to prioritize?), the target population (should the population at large be interviewed or just forest dwellers?), investments in data analysis of high policy relevance (which causal relationships require most urgent analysis?), and appropriate formats for dissemination (web-based databases, short policy briefs or scientific research papers?). Unless the NFA is adjusted to meet such stakeholder preferences, it is unlikely that the results will have the desired impact on decision-making. Moreover, the lack of documentation may also make it more difficult for participants in the consultation process to assess the extent to which their suggestions have been taken into account.

Another source of information is FAO and its Global Forest Resource Assessment (FRA)

programme. During FRA 2010, member countries were asked to report on about 20 variables. About half of these variables require data collection through interviews for estimation. Table 1 lists several of the FRA variables that NFA teams may gather through interviews.

Appendix 1 presents plausible formats for the systematic collection of this core NFA data through two types of personal interviews in the field: (i) key informant interviews and (ii) household interviews. These questionnaire samples are based on the NFA of the Government of Tanzania, and as such reflect the priority information needs of that country. Each NFA country team would need to decide which variables to measure through interviews. After agreeing on an appropriate format, each team should carry out extensive pre-tests of the agreed-upon interview protocol (see section , p. 61).

4. Who should be interviewed?

4.1 Strategies for selecting a representative sample

The selection of interview participants is a critical step in securing useful and high-quality data. Before designing a sampling strategy, which will determine how interviewees will

Table 1: Links between NFA outputs and interview variables

Outputs	Relevant interview variables
Biodiversity: human impacts on biodiversity	• Perceived tendencies of supply and demand for endangered species • Services derived from the existence of biodiversity (ecotourism)
Non-wood forest products: food, medicine, crafts, construction	• List of NWFP products harvested (occurrence) • Perceived tendencies of supply and demand of NWFPs • Who harvests the product? • Rank, seasonality, changes in extraction, access, rights, etc.
Wood products: annual supply of timber and other woody forest products (such as fuel-wood)	• List of wood products harvested (occurrence) • Perceived tendencies of supply and demand of wood • Frequency of extraction, rank, seasonality, changes in harvest patterns, etc. • Rank, seasonality, changes in extraction, access, rights, etc.
Services: social and poverty alleviation, economic, environmental	• List of types of existing services derived from trees and forests • User perceptions of demand and supply for services
Accessibility: to trees, forests and markets (distance to forest, hospital, school, roads)	• Distance to roads, markets, schools, health clinic • Distance to area of sample plots
Tenure: user rights to tree and forest products	• Types of legal user rights to tree and forests

be identified and selected for interviews, the NFA management must define the main population of interest.

Defining the population of interest is a process that involves reaching an agreement among several NFA stakeholders concerning the desired outputs of the NFA. First, what is the primary objective of including interviews in the NFA? Is it to gain a better understanding of the importance of forest use for the entire national population? Or is there a particular subgroup of the population whose relationship with forests is more important to understand? Any definition of a population of interest needs to be firmly anchored in the responses to these questions and there should be an agreement among as many NFA stakeholders as possible.

For many NFAs the most important population of interest is **people who live in or near forests** because many of these people depend directly on forests for their livelihoods, and as such constitute a socio-economically very vulnerable group in many societies. Very little systematic data exist in most countries for this group of people. This dearth of data is a problem for several reasons. First, lack of good data on forest-dependent people makes it very difficult for policy-makers to develop interventions that can help local people who benefit from forest use, while at the same time ensuring the long-term sustainability of the resource. Second, this group of citizens often possess substantial knowledgeable regarding the variety of products and services that people, local or not, derive from a given forest area.

Third, people who live in or near forests often have a strong understanding of why some forestry-related interventions are more effective than others. For example, forest users can provide accurate observation-based assessments of performance of a variety of governance actors, such as government agency representatives, NGOs, local community organizations and international development projects. Finally, these local forest users are in a unique position to identify requirements to improve the performance of forest policy interventions in a given context, at least with regard to their own interactions with forest resources.

Numerous definitions exist of populations of interest, these justifications notwithstanding. The choice of target population, however, will depend on the country's priority needs. Depending on the outcome of the needs assessment, possible definitions of populations of interest may include: (i) the entire nation's population at large; (ii) forestry firms; (iii) forest owners; (iv) associations of forest users; (v) communities participating in community forestry activities; (vi) the primary agents of deforestation; (vii) indigenous peoples, and many others.

4.2 The case of Tanzania

This subsection illustrates the process of developing a sampling strategy for the interview component of an NFA. It focuses on a case study in Tanzania, an FAO partner country in the development of a comprehensive and integrated data collection process for NFAs.

The Government of Tanzania defined its main population of interest as **people who live in or near forests**. FAO's technical advice was sought to develop a sampling strategy that would permit estimation of several parameters of interest for this population. FAO supported a technical study by a team of social scientists, who put forth a set of technical recommendations (Kessy and Andersson, 2010) and subsequently produced a field manual for the collection of data through interviews in the field (NAFORMA, 2011).

Sampling design for interviews in Tanzania

A team of national and international forest inventory experts developed a sampling design for direct measurement of forest vegetation, the main purpose of which was to deliver estimates of forest parameters of particular interest at the desired level of precision for

each of the reporting units. The resulting model-based design uses the predicted spatial variability of total timber volumes (as a proxy for forest carbon) as the main parameter of interest. It consisted of 3 500 sampling clusters, most of which are located in forested areas (for more details on the biophysical sampling design, see Tomppo *et al.*, 2010).

The Government of Tanzania decided to replicate the sampling design developed for the biophysical measurements for the interview component. There were two important reasons behind this decision. First, this coupled design allows for a close analytical link between biophysical and socio-economic data, which in turn will strengthen the explanatory power and policy relevance of the interview data. Second, it will produce a relatively unbiased sample of the population of primary interest: people living in or near forests. Figure 1 below illustrates the relationship between the sampling units (SU) for the biophysical and interview data collection components in Tanzania's NFA.

The sampling unit for household interviews is determined by drawing a circle with a 2 km radius around the centre of the plot cluster for biophysical measurements. Two types of interviews are carried out in each of these sampling units: (i) household interviews and (ii) key informant interviews.

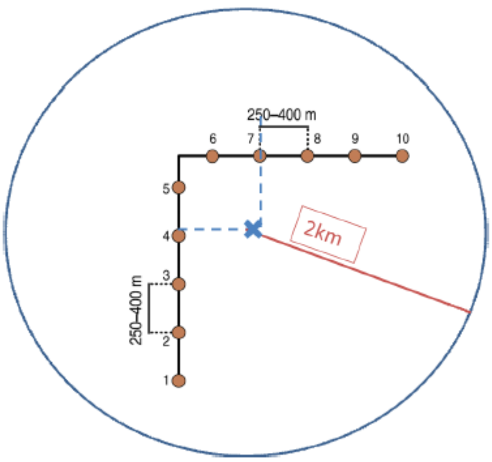


Figure 1. Relationship between biophysical and interview components

Household interviews are carried out with a probability sample of household representatives. In each of the sampling units, representatives of four households are selected for an interview. Three more households are selected as back-up households in the event that residents are absent in any of the selected dwellings. These households are identified and mapped (as far as possible) using high-resolution satellite imagery and with the help of key informants, before going to the field. The seven households are selected systematically in each sampling unit by choosing the households nearest to the centre of the 2 km circle. Figure 2 provides an example of such a selection process.

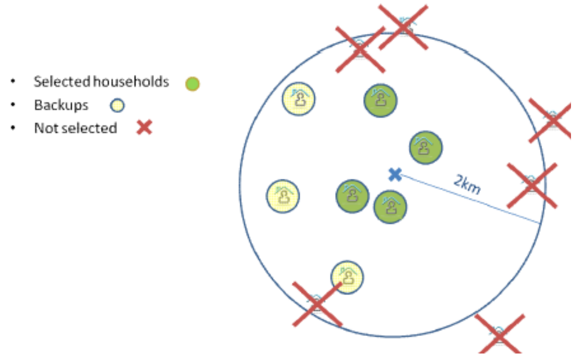


Figure 2: Household selection procedure in Tanzania

Interviewers work in pairs and consist of one man and one woman. Once a household has been selected, the interviewers ask to interview both household heads (man and woman) if both of them are available. Research has shown that household surveys produce biased results if only the male or female member is interviewed, and NAFORMA wants to minimize such gender bias to the extent possible (Fischer *et al.*, 2010). Each household interview lasts for 45–50 minutes and consists of a total of 45 questions (see Appendix 1 for a suggested household questionnaire).

Key informants are individuals who are especially knowledgeable about the use of forest resources in the area of the sampling unit. Examples include the property owners themselves, local village authorities and elders. Interviews are carried out with a non-probability sample of such individuals

because it is not possible to define, *a priori,* the probability for any particular individual of being selected, as selection is to a large extent determined by the opinion of local people and government officials, who are asked to identify key informants in each sampling unit. The questions asked the key informants to focus principally on issues of property rights, environmental conditions and trends, and historical land uses.

There are three reasons for adding interviews with key informants as a second form of socio-economic data collection. First, they *complement* the data provided by households. Second, they allow for *triangulation* of data collected in household interviews. And finally, because of the spatially explicit nature of these interviews – which use satellite imagery and aerial photos as part of the interview process – they strengthen the *link between socio-economic and biophysical data* in NAFORMA.

Before the interview starts, the interviewer should ensure that the key informant is aware of the exact boundaries of the SU. An aerial photograph, satellite image or map may be used for this purpose. By asking questions about forest use in the SU in particular, rather than forest use in general, as is the case for the household interviews, the key informant interviews provide critical data about the location of user-resource interactions. Appendix 2 (p. 74) includes a sample of questions for key informants, based on the NFA in Tanzania.

5. How should the interview be conducted?

5.1 Suggested interview techniques

Interviews play an important role in NFA data collection and are not easy to perform well. Good interview techniques are acquired through experience, training and by following certain procedures. This section suggests several methods and techniques for NFA personnel conducting interviews. These methods are especially important in situations where the interviewee is illiterate, not accustomed to formal surveys, or suspicious of the motives behind the interview. At least one member of the field team should have extensive prior experience in conducting semi-structured interviews with rural people.

Correct application of these methods by NFA field personnel decreases concern over the reliability of the final results. But even if the majority of consultants apply these recommended methods, it is hard to estimate the degree of total uncertainty unless the quality of the NFA data is tested. The next section defines three critical criteria for assessing the quality of NFA data.

6. What is the best way to verify data quality?

Forest use can be socially very complex, especially when it involves multiple users with varied characteristics. The challenge for the design of the NFA interview component is to gather quality data that capture this variability at the national level. This section provides advice on how to assess the quality of results from the interview component of the NFA. Each NFA team should test its data during the fieldwork phase for: (i) representativeness, (ii) reliability and (iii) validity.

6.1 Test of representativeness

The technical team should periodically evaluate the degree of representativeness of the sample of interviewees at the strata level. For example, if the national government has established the district as the lowest level of reporting unit for a country, an evaluation of the representativeness should include a series of simple statistical analyses that estimate precision for several parameters of interest for the districts of a country.

Moving averages and F-tests can be used

Pointers for Conducting Field Interviews

Building rapport: A good working relationship with the local people is easier to establish when an interviewer is well prepared, shows respect, and remembers that the fieldworkers are there to learn from the forest users about how they are using and benefiting from their local forest.

Taking notes: It is not always appropriate to take notes. Always ask the interviewee for permission. If permission is granted, explain clearly what the notes will be used for, and after the interview summarize what you have written. Use a small notebook, never an official-looking questionnaire form.

Rural women are often busy, and are sometimes shy with strangers, regardless of whether the stranger is a man or a woman. **Fieldworkers should be sensitive to the constraints facing women** when undertaking interviews. Preferably, a woman should interview the women, respecting the female space.

Use an **open-ended questioning style** that seeks explanations and opinions rather than yes or no answers. Ask, for example, "where do you collect fuelwood?" Rather than, "do you cut fuelwood from the government forest?"(Jackson and Ingles, 1998). To relate it to the sample site, follow up with "Do you also collect in this part of the forest" (pointing at the sample site on a map).

Probing and the use of non-leading "helper questions": Probing is an art learned through careful practice. Ask several questions around a subtopic to ensure understanding (both yours and the participants'). Use non-leading helper questions such as: Who? What? Where? When? Why? How? How many? How often? and so forth (Messerschmidt, 1995).

Giving interviewees a chance to ask you questions. At some point in the interview you might ask, "Are there any questions you would like to ask us?" This is likely to put the respondent(s) more at ease, as it shows that the interview is not totally one-sided, and provides an opportunity for the interviewee to mention any points they wish to clarify.

Use maps or aerial photographs to stimulate discussion about local forest use. Looking at aerial photos or maps is a natural moment to discuss aspects of access to the sample site, and land use of the sample site area and surroundings. It also provides a chance to obtain information on landmarks, locations and names, administrative boundaries and forest products, including seasonal availability.

Community mapping: Local people can be asked to draw their community and surroundings. A facilitator might help to start the activity by drawing a reference point, such as a road. For the remainder of the exercise, however, the people should draw their own map with minimal interference. Questions from the facilitator regarding ownership, what is harvested in different parts, and so on, can be discussed with reference to the map.

Direct observation might seem obvious, but is nevertheless very important. The field crew must be attentive and observe the sample site and surroundings, noting the general land use, facilities such as shops, schools and markets, and housing and infrastructure. A good interviewer understands the perspective of the local people and is able to identify with them.

Transect walk is a walk designed to follow a specific route, often along a contour line of different elevations and different ecological zones. Transect walks can help to address a particular problem associated with NFA interviews – the difficulty of linking interview information to the specific plot area where the trees have been measured. It is unlikely that valid user information will be acquired at the plot level unless each interview includes a transect walk with the interviewee.

Source: Branthomme, 2009.

to ascertain whether the complexities of the country's forest use are being captured by the measurements in the sampled sites. To be meaningful, such tests need to be carried out continuously throughout the data collection phase. As NFA personnel enter information from interviews into the database, the technical unit should test how new data affect the aggregate variance and moving averages of key variables at the different regional strata

levels. Such a processing method enables the teams to correct for possible under-sampling or biased sampling in the earlier sites of the project by increasing the sampling intensity of interviewees in the latter sites. These tests provide an independent quality control of tests performed by field teams when they apply the adaptive sampling techniques, described above.

6.2 Reliability tests

According to King *et al.* (1994), if the same measurement procedure is applied in the same way you will always get the same result. Zeller and Carmines (1980) illustrated the concept of reliability with the following example: "If a well-anchored rifle is fired but the shots are widely scattered about a target, the rifle is unreliable" (ibid.: 48). In a more formal and perhaps nuanced way, reliability is concerned with the degree to which measurements are repeatable and consistent (Nunnally, 1967).

There is no such thing as perfectly reliable measurements in the social sciences. Because one seldom deals with direct measurements but instead with indirect estimates of variables, there is always some degree of human-induced error involved in measurements of social phenomena. These measurement errors can be either random or systematic in character. Interpreting data that are liable to different kinds of possible measurement problems can result in difficulties. In this context, verifying the reliability of measurements is even more important (Gujarati, 1995). To this end, social science research has produced a variety of testing procedures.

One test of reliability available to surveyors is to try to reproduce the same measures. The same researcher may use a different set of measurement methods or a different researcher may use the same methods. A more formal test of reliability involves examining the two main characteristics of the reliability concept: *stability* (whether a measurement is repeatable) and *equivalence* (whether a measurement is consistent).

Stability tests involve analysing the same measure for the same population at more than one point in time. This test is often referred to as the test-retest correlation test. In such analyses the researcher correlates the same measurements at different points in time. If the two separate sets of measurements produce exactly the same results, there is a perfect correlation of 1.00. Since the correlation score is likely to be less than a perfect 1.00, most social scientist researchers consider that a measure is reliable if the test-retest correlation score is greater than $r = 0.70$ (Litwin, 1995).

Equivalence tests involve measuring multiple indicators of the target concept at a single point in time, using the split-half method. The researcher divides the interview variables (that measure the same concept) into two halves and then correlates the values of the two halves. The higher the correlation score, the higher the reliability (Stanley, 1971).[1] Needless to say, applying the split-half method requires an instrument that gauges multiple measures of the same concept.

The technical unit will need to undertake periodic reliability tests as field consultants add more field data. This practice functions as an early warning system to detect problems with the reliability of reported information.

6.3 Validity tests

Using the same rifle analogy used to explain reliability, Zeller and Carmines (1980) offer the following illustration of validity: "If the shots from a well-anchored rifle hit exactly the same location but not the proper target, the targeting of the rifle is consistent (and hence reliable) but it did not hit the location it was supposed to (and hence it is not valid)" (ibid.: 77). The illustration shows how a set of indicators that are perfectly reliable may not represent the concept they have been chosen

1 The split-half method has been criticized because the analyst can manipulate the results of the test through the way in which the indicators are divided. As a response to this critique, several other techniques have been developed to test the consistency aspects of reliability of measurements, including Cronbach's alpha, principal component and factor analyses (e.g. see Armor, 1974; Cronbach, 1951; Novick and Lewis, 1967).

to measure, because they are plagued by systematic error or bias.

The interview component of the NFA is concerned with measuring a series of both abstract and complex concepts. Since these concepts are not directly observable variables, proxy variables are applied. Precisely because proxy measures are imperfect, it is important to assess how well they reflect the concepts that the interviews seek to measure.

There are no mechanical blueprint tests that can be applied to test validity (Litwin, 1995; Zeller and Carmines, 1980). In spite of this difficulty, social science research views validity tests as a crucial step. It has become a norm in social science research to document and describe the validation process in the presentation of the results (Fink, 1995; King *et al.*, 1993; Litwin, 1995).

Bohrstedt (1970) suggests that, "because the fallibility of any single set of measures, we need to validate our measure of *X* by several independent measures, all of which supposedly measure *X*" (1970: 95). Depending on the most likely source of non-random errors, the approach and evaluation criteria chosen are likely to vary with the particular objective of the study.

In the case of the NFA, it is recommended that an independent team of experts carry out validation by comparing the NFA survey results with their own in-depth measurements. Such an expert team would undertake measurement at a selected number of sites to obtain an idea of the validity of the original measurements (Fink, 1995; Litwin, 1995). This kind of test is probably the most rigorous, as it: (i) assesses the level of uncertainty for all variables measured; (ii) complements the interview data with in-depth information on issues of central importance for policy (i.e. describing the role of forestry in alleviating rural poverty, the importance of forestry in efforts to improve food security, etc.); and (iii) strengthens the accountability mechanism between the technical unit and the consultants.

The case study protocol developed by the International Forest Resources and Institutions (IFRI) Research Program[2] provides an excellent guide for independent validation of the NFA interview component (Gibson, McKean and Ostrom, 2000; Ostrom and Wertime, 1993). Following the guidelines of the IFRI Program, the selected case study sites could be established as permanent reference sites to be revisited every 5–10 years, to study the effects of changing policy and market conditions on local patterns of tree and forest use. The existence of these sites as reference cases will help NFA personnel to interpret the results of the study, put them into concrete contexts, provide reliable data on public policy impacts in specific locations, and reveal the practical implications of the results for particular forest-user groups in society.

The validity of the interviews may be further strengthened by a survey pre-test (Fowlern, 1988). The pre-test complements the above test by giving the surveyor a chance to identify questions that are not effective and that seem to generate a large proportion of no-opinion responses.[3] Analysis of responses to the pre-test can help to identify potentially problematic questions and allow researchers to modify lengthy, emotionally loaded, confusing and suggestive wordings (Parten, 1950; Patton, 2001: Chapter 7; Wilkin, Hallam and Doggett, 1992).

The validation tests may indeed demonstrate that the methods used in the NFA are both reliable and valid, but until such tests are actually carried out, the quality of NFA information will remain unknown. The three types of tests mentioned above enable the level of uncertainty associated with the NFA findings to be defined. Presenting the results of such testing procedures is likely to improve perceptions of the quality of NFA information products among users.

2 For more information, see: www.umich.edu/~ifri

3 If a very large proportion of responses are no-opinion responses, the validity of the survey instruments and/or the methods used should be viewed with caution.

7. Conclusion

The quality of the NFA study is related directly to the questions the NFA team asks, who they ask, how they ask their questions and how they go about verifying the information obtained. By paying careful attention to the advice offered in this chapter, the NFA team may minimize the problems relating to the reliability and validity of the interview data. However, the reliability and validity of interview data will never be perfect. For this reason, the credibility of the NFA results hinges on how the NFA team presents its estimate of uncertainty.

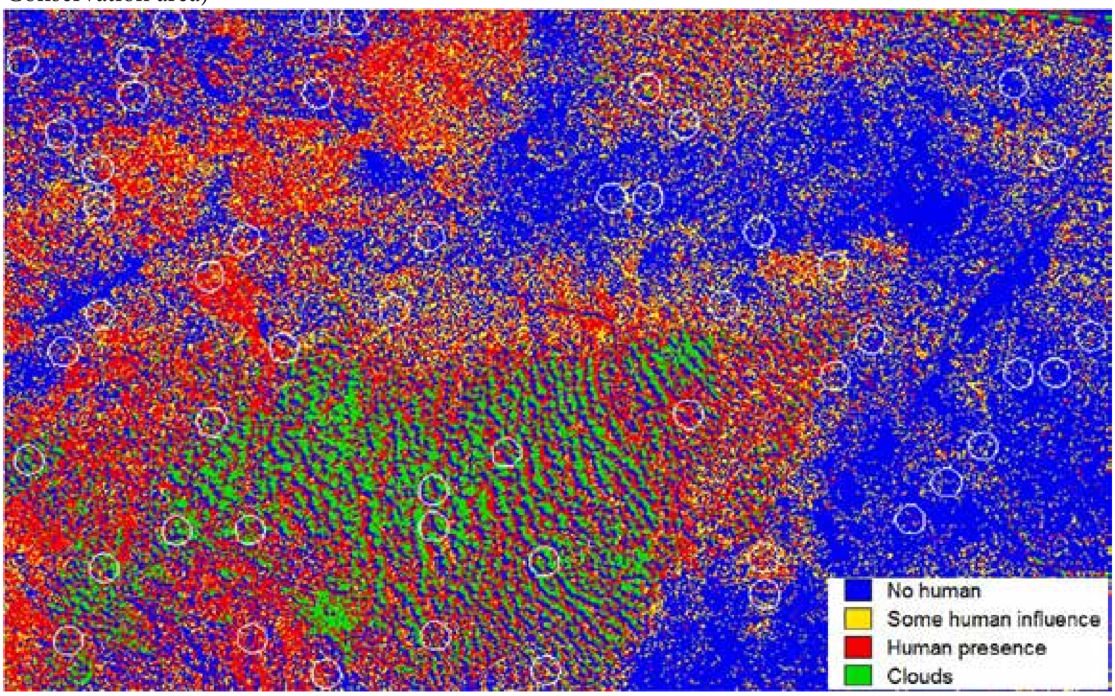
Without a good description of the degree of uncertainty, a particular finding becomes virtually impossible to interpret. Even if a measurement is of a qualitative nature, such as interpreted information from forest interviews with key informants, it is extremely important to estimate explicitly the bounds of uncertainty for the conclusions drawn from the results. It is possible to estimate the degree of uncertainty by considering how observed limitations in reliability and validity might influence the study's findings. Presenting the study's limitations up-front and in a systematic fashion, strengthens the scientific merit of the results and increases the credibility of the study.

Self-study exercise 1: Testing the sampling design

One of the critical steps in the preparatory phases for the field interview component of any NFA is to test the sampling design. The purpose of such testing is to determine the extent to which a particular sampling design would generate a representative sample of forest users. This exercise describes the basic steps for conducting such a test, based on the recent experience of the NFA in Tanzania. A variation of this test should be performed as a self-study exercise for any prospective NFA project.

The project used high-resolution satellite imagery (the panchromatic band of Landsat 7, with a 15 m spatial resolution) to obtain a better sense of the implications of the proposed sampling design in terms of numbers of likely field interviews. The satellite image was

Map 1. Spatial distribution of sampling units in the area west of Morogoro (including the Eastern Arc Conservation area)



Note: The white circles represent the sampling units.

converted to a shape file and imported into ArcGIS. The coordinates for the sampling units in the interview were overlaid in the GIS. Map 1 shows the test results for the area west of Morogoro, Tanzania. This area was selected for the test because it represents a critical case for the sampling design, being much less densely populated than most other areas of the country. If the proposed sampling design performs satisfactorily (i.e. shows that a sufficient number of households are likely to be selected in each reporting unit), it is reasonable to conclude that the design will perform at least as well in other areas.

Although the 15 m spatial resolution did not allow the location of individual dwellings to be positively distinguished, the imagery did provide useful, estimating that the proportion of sampling units would have a high probability of having no household dwellings within them. If many sample units are void of households, there is a risk of not having a representative sample of forest users.

For the area used in this test, it appears that about 15 out of 46 sample units (33 percent) have very little or no human presence, and consequently there is a very low probability of finding any households living within these units. The results indicate a reasonable chance of people living near the vast majority of sampling units in this particular area. These results also indicate that the sampling design seems viable, since the area is less populated than most other parts of the country. However, further empirical tests are recommended, using the same approach presented here. Such tests would seek to answer the specific question of how many households should be sampled in each of the 26 regions of Tanzania, and determine whether the given sample sizes are sufficient to achieve an 8 percent sampling error at the regional level. Additional information is required to determine this point. The following exercise provides a description of such information may be acquired.

Self-study exercise 2: Field testing of the interview questionnaire

Three factors, often overlooked in survey work, are very important influences on the quality of interview data: (i) the interview skills of the people conducting the interviews; (ii) the content and clarity of questionnaires; and (iii) the length of the interview. All of these factors may be addressed through careful preparation during the planning stage of the NFA. In this self-study exercise, it is suggested that NFA personnel engage in a process of training and field-testing of interview questionnaires. This process could involve several steps:

1. Invite NFA personnel to a one-day workshop.
2. In the workshop, divide participants into groups to propose variables of interest to be measured through interviews. For simplicity, ask groups to focus on a maximum of two variables each.
3. Ask groups to develop interview questions directed at specific target actors (households or key informants) that can generate measures for the variables of interest.
4. Based on group inputs, compile all proposed interview questions into one interview questionnaire for household interviews and another for key informants.
5. Divide workshop participants into groups of three. One person will act as an interviewer, one as an interviewee, and the third as a silent observer and timekeeper. The purpose of this exercise is to identify problematic questions, suggest improvements, and obtain a sense of the total time needed for each interview.
6. In plenary, go through each questionnaire, one question at a time to review possible suggestions for modifications.

7. Circulate a new version of the questionnaires, and if possible repeat exercise 5.
8. Ensure that each interview may be completed in no more than 45 minutes. Make necessary adjustments to meet this objective.
9. Repeat exercise 5 in a simple field setting, preferably in a community of forest users with which NFA personnel enjoy a good rapport and where there is a willingness among villagers to engage in a workshop of this sort. Make sure that community members are properly introduced to the purpose of the workshops and that they are duly compensated for their participation.
10. After conducting several ideas in the field, gather all participants to discuss the content of the questionnaires, one question at a time. Make corresponding adjustments to the questionnaires.

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Appendix 1. Sample household survey instrument

Task	Date(s)			By whom?	Status
	Year	Month	Day		
Field interview completed					
Questionnaire checked					
Data entered into database					
Data entry checked and approved					

Household number (HH1, HH2, etc. or X-HH1, X-HH2)	HH#	
Cluster number	#	
Distance from household to nearest forest	metres	
Village to which household belongs (not necessarily the nearest one)	Name	
Ward to which household belongs	Name	
District to which household belongs	Name	
GPS location of household	[UTM format]	
Duration of interview	Starting time	Ending time

A. Control information

B. Identification and location of household

C. Household characteristics

1. How many members are there in this household (people who share meals on a daily basis)? _______ind.
2. How many members did this household have five years ago? ______ individuals.
3. For how long has the head of this household lived in this location? ________ years.
4. What is the birthplace of the head of the household? ______________________(name of district)
5. Who are the heads of the household (head of household and spouse(s)? (fill in the table below)

1. Position in household	2. Person interviewed (0 = no; 1 = yes)	3. Age	4. Gender (0 = male; 1 = female)	5. Education (highest level attained)*
Head				
Spouse				
Other (specify):				

* **CODES:** 1 = none; 2 = primary school; 3 = secondary school; 4 = college/university; 5 = other (please specify).

D. Household assets

1. Describe the house in which this household lives (enumerator's observation)

a. What is the type of material of (most of) the walls?*	
b. What is the type of material of (most of) the roof?**	

CODES: * 1 = mud and poles/withies; 2 = wooden (boards); 3 = iron (or other metal) sheets; 4 = mud bricks; 5 = burnt bricks; 6 = concrete bricks, or concrete; 7 =reeds/straw/grass/fibre; 9 = other (please specify). **1 = thatch; 2 = iron or other metal sheets; 3 = tiles; 9 = other (please specify).

2. Please indicate the number of the following items that are owned by the household:

Item	Number of units
Cattle (excluding oxen)	
Goats/sheep	
Poultry	
Pigs	
Draught animals (oxen, donkey, etc.)	
Car/truck	
Plow	
Carts/wheelbarrow	
Bicycle	
Phone	
TV	
Radio	
Other items, specify	

3. Please indicate the household's main sources of energy and how they are acquired.

Energy source used	Acquisition methods*	Quantity/month consumed	End purposes**
Firewood		Head loads	
Charcoal		bags	
Gas		kg	
Kerosene		litre	
Electricity		TShs	
Other (specify) ______			

CODES: * 1 = own collection; 2 = purchase; 3 = other, **1 = cooking; 2 = lighting; 3 = heating; 4 = other.

If firewood or charcoal were mentioned as energy sources, please ask the following questions about availability of alternative energy sources (if not, skip to question 4):

3a. Are any alternatives to firewood/charcoal available here, but not used? ______.

CODES: 1 =yes; 0 =no.

3b. If yes, which sources are available? ______.

CODES: 1 = gas; 2 = electricity; 3 = kerosene; 4 = solar panels; 5 = other (please specify).

3c. What are the main reasons for not using these sources instead of firewood/charcoal? ______.

CODES: 1 = too expensive; 2 = different preferences; 3 = other reasons (please specify).

4. Please indicate the amount of land that you currently own and have access to:

Category	**Area owned individually (in acres or hectares)**		**Do outsiders respect boundaries?***	**Area of land owned communally (to which the household has access)****		**Do outsiders respect boundaries?***
	Area	**Unit (specify)**		**Area**	**Unit (specify)**	
Cropland (not irrigated)						
Cropland (irrigated)						
Pasture (natural or planted)						
Forested land (including woodlots, silvipasture, etc.)						
Other vegetation types (specify)______________						
Rented or borrowed land						

CODES: * 1= yes, everybody; 2 = most people; 3 = most do not respect; NA = not applicable; ** Estimates, including ranges of value (i.e. 10-15 acres) permitted.

5. Has the household's private land property changed over the last five years? _______

CODES: a = yes, increased; b =yes, decreased; c =no change. **If there is no change**, please skip to E.1

6. If area of private land property has changed, by how much did it change? _______acres or _______hectares

7. Why did this change occur? (Text to indicate source of change) ____________________________

____

E. Household food security and risk

1. In the past year, where did the household's food come from?

Source	**Months food lasts**
Food grown on land owned and cultivated by household	
Food grown on land cultivated but not owned by household (e.g. land rented)	
Food purchased from the market	
Food from forest (mushroom, fruits, bushmeat, etc.)	
Food given as gift or food aid	
Other (please specify): ___________________________	

2. Which months of the year do you experience food shortages in the household? _____ month/ NA

3. During critical food shortage months does your household use forest products to meet food needs?
☐ Yes ☐ No **If no, please go to question 5**

4. If yes, please indicate the forest products that are collected to supplement household food supplies during periods of food shortage:

Product	**Species**	**Quantity collected/week**	**Unit**	**Rank (1–5)**
Tubers				
Wild vegetables				
Mushrooms				
Honey				
Fruits				
Others (please specify)________				

5. Has your household faced any unexpectedly large expenditures during the past 12 months? ☐ Yes ☐ No **If no, please go to question 7**

6. If yes, what event(s) caused this shortfall? (Fill in the table below. Multiple answers are possible.)

Event	**Existence***	**Response****
Serious crop failure (drought, pests, floods)		
Serious illness or disability in the family		
Death of productive age-group adult		
Land loss (expropriation, etc.)		
Major livestock loss (theft, drought, etc.)		
Social events (wedding, funeral, religious events)		
Other (please specify) ____________________		

CODES: *1 = yes; 0 = no **multiple answers possible: 1 = harvest more forest products; 2 = harvest more wild foods not found in the forest; 3 = harvest more agricultural products; 4 = spend cash savings; 5 = sell assets (i.e. land, livestock, etc.); 6 = do extra casual labour; 7 = assistance from friends or relatives; 8 = assistance from NGO, community organization, religious organization or similar; 9 = get loan from money lender, credit associations, bank etc.; 10 = tried to reduce household spending; 11 = did nothing in particular; 99 = other (please specify).

7. In the last five years have there been any major disturbances to the local forests that decreased the availability of forest products ☐ Yes ☐ No **If no, please go to question F.1**

8. If yes, what were these events and how did your household cope with this shortfall?

Event	Existence*	Responses (multiple answers possible)**
Fire		
Disease		
Lumbering		
Encroachment		
Grazing		
Charcoal making		
Other (please specify)____________		

CODES: *1 = yes; 0 = no **1 = by harvesting fewer forest products; 2 = by harvesting more of other forest products; 3 = no change in harvesting; 4 = by harvesting from a different forest; 9 = other (please specify).

F. Household income

1. In the past **12 months**, which have been the most important sources of income for the household? *If no income was received from a particular source, please record "NA".*

Income source	Source of subsistence *	Rank subsistence	Source of cash income*	Cash income (TZS)
Forest products (timber, game, charcoal, etc.)				
Agriculture				
Livestock				
Wage income				
Income from own business				
Remittances				
Other sources (please specify) _________				

CODES: *1 = yes; 0 = no.

G. Household opinions

Please indicate the extent to which you agree with the following statements (using a scale from 1 to 5, 1 meaning completely disagree and 5 meaning fully agree.)

1. In your opinion do you think households in this area can reduce their consumption of forest products? ___
Comment: ____

2. Do you think that local communities in this area are more effective in protecting forests than government officials? ___
Comment: ____

3. Do you think that the rules regarding the use of forest resources in this area are fair to everyone? ___
Comment: ____

4. Do you think that the penalties for breaking forest-use rules in this area are fair to everyone? ___
Comment: ____

H. Forest products and services

1. Please list all tree and forest products used in the past 12 months. For the three most important products for the households, please characterize demand, supply, etc. (variables in shaded portions of the table)

All tree and forest products				**For top three products ONLY**										
Product category	Species names (multiple)	Land use category	Rank	Distance to source	Who harvests?	Harvesting change	Quantity harvested	Unit (specify)	End use	Rights	Conflicts	Local rules	Legislation awareness	Legislation enforcement

2. Please list all forest-related services that the household has benefited from in the past 12 months.

Environmental services from forests				**If payment was received:**	
Service type	Exists*	Rank	Payment*	Payment from (type organization)**	Amount (TZS)
Fresh water/ water conservation					
Climate regulation					
Windbreak					
Recreation/ tourism					
Soil protection					
Shade					
Aesthetic					
Employment					
Other (please specify)					

CODES: *1 = yes; 0 = no; ** check manual.

3. During the last five years, how have the following land-use characteristics changed in this locality?

Land use	**Change**
Cultivated land	
Forest land	
Natural surface water (excluding man-made reservoirs)	

CODES: 1 = decrease; 2 = stable; 3 = increase.

I. Participation in organizations and forest-user groups

We are interested in learning about your household's involvement in groups that seek to improve forest use (i.e. these can be either formal or informal groups that undertake forest-use activities).

1. Are you aware of any initiatives relating to Participatory Forest Management **CODES:** (1 = yes; 0 = no).	
2. Are there any other initiatives in this area that work on forest-related issues? **CODES:** 1 = yes; 0 = no. If "no", go to question 6.	
3. Are you or any member of your household involved in a group that organizes activities relating to management of the forest (i.e. fire fighting, patrolling, tourism, tree planting, etc.)? **CODES:** 1 = yes; 0 = no. If "no", go to question 6.	
4. What is the name of the group(s) your household is involved with?	
5. Overall, how would you say the existence of the organization has affected the benefits that the household gets from the forest? **CODES:** 1 = large negative effect; 2 = small negative effect; 3 = no effect; 4 = small positive effect; 5 = large positive effect.	
6. How frequently does the group/community that you belong to actively monitor and patrol the forests to detect intruders and thieves of forest products? **CODES:** 0 = never; 1 = hardly ever; 2 = regularly (>1 time/month); 3 = frequently (>1 time/week).	
7. How frequently do government officials (district, region, central) visit the forest area? **CODES:** 0 = never; 1= hardly ever; 2 = regularly (>1 time/month); 3 = frequently (>1 time/week)	
8. In the past 12 months, approximately how many individuals have been caught breaking the established rules of forest use? **CODES:** 0 = none; 1 = <5; 2 = 5-10; 3 = 10-20; 4 =>20.	
9. Who decided which punishment these individuals should receive? CODES: 1 = local community group that made the rules; 2 = village council; 3 = district government; 4 = central government; 5 = court of law; 6 = other (specify).	

J. Relationships with forestry organizations

1. Which organizations do you consider to be the most important for your participation in forest-related activities? (If the respondent perceives no organization to be important, please mark "NA" above the table.)

Type of organization	**Rank (1-3)**	**Frequency of interaction***
National government		
District government		
Village government		
NGO (WWF, IUCN, etc.) please specify ______________		
Other (please specify)____________		

CODES: *number of meetings per year: 0 = none, 1 = 1-5 times; 2 = 5-10; 3 = 10-15; 4 = 15-20; 5 =>20.

Appendix 2. Sample questionnaire for key informant interviews

All of the questions on this form are asked after making sure that the key informant is aware of where the boundaries of the sampling unit (SU) are. An aerial photograph, satellite image or map should be used to make the interview as spatially explicit as possible. By asking questions about forest use in the SU in particular, rather than forest use in general as is the case for the household interviews, the key informant interviews would provide critical data about the location of resource use. The enumerators should follow the instructions in the Field Manual for how to code the responses to the questions.

KEY INFORMANT INTERVIEW FORM

Cluster #: Please indicate the official code for the cluster: ___________

1. Who is the **Informant**? ______________________________ Code according to option list in Field Manual (multiple choice possible)

2. What is the **total number of households** that reside within the boundaries of the 2 km sampling unit? ________

3. Compared with the rest of the population in the district, how would you characterize the general **health condition** of the population living near and inside the sampling unit? Choose **one** option from the option list in the Field Manual: ___

4. Which are the three most important **products** that most local people harvest from this area (refer to the area within the SU – point to a 2 km circle on the map/image)?
   Product 1: ____________________________
   Product 2: ____________________________
   Product 3: ____________________________

5. Approximately how many **households** (regardless of where they live) regularly harvest products from this particular area (refer to the area within the SU – point to a 2 km circle on the map/image)? _________ households

6. Are there any rules (informal or formal) that constrain local households' uses of products?
   ☐ Yes ☐ No **If no, go to Q9**.

7. If yes, what is the **origin** of these rules? ____ (mark all applicable options from codes in the Field Manual)

8. What is the distance from the centre of the SU to the following infrastructure features?
   a. _____ km to nearest **all-weather road**
   b. _____ km to nearest **seasonal road**
   c. _____ km to nearest **village**
   d. _____ km to nearest **health centre**
   e. _____ km to nearest **school**
   f. _____ km to nearest **food market**

9. When was this **settlement established** (when did the local household dwellings arrive to the area)? Choose one option from the Field Manual's list____

10. What is the **population trend** for the past 5 years for this area? Choose one option from the Field Manual's list____

11. What are some of the **major historical** events that have affected local people and their land use in this area? _____ To be indicated according to the Field Manual's option list mark all options that apply).

12. Have there been any **efforts to manage** or somehow **organize the forest resource use** within this area? ____ ☐ Yes ☐ No **If no, go to Q17**.

13. If yes, was there a particular **leader** of this effort? ____ Mark all options that apply, according to the list in the Field Manual.

14. Is the effort described in Question 14 **still taking place**? ☐ Yes ☐ No

15. In your opinion, to what degree would you consider the efforts to manage and order forest use in this area to have been successful? Choose one option from the Field Manual ____

16. Is any part of the forestland within the sampling unit currently under any kind of forest or woodland **management plan**? Choose one alternative from the Field Manual _____

17. What type of **management arrangement** between the landowner and other groups exist for this area? ____ To be indicated according to the option list in the Field Manual.

18. To what extent is this particular area affected by **large-scale**, illegal forestry activities? Choose one option according to the list in the Field Manual: ____

19. If a local person engages in **large-scale** illegal activities (i.e. large timber operation, industrial charcoal making, etc.) in this area, in your opinion, what is the likelihood of anybody detecting or stopping this activity? Choose one option according to the list in the Field Manual____

20. If a local person engages in **small-scale** illegal activities (i.e. cutting of timber, charcoal making for local markets, etc.), in your opinion, what is the likelihood of anybody detecting or stopping this activity? Choose **one** option according to the list in the Field Manual ____

21. Are there any local individuals who have shown **leadership** to organize forest activities among forest users in this area? ☐ Yes ☐ No

22. What is the name of the most active **forestry organization** (external to the local community/ settlement) in this district and region? ______________________________

23. If applicable, how far away from the centre of the SU does this forestry organization (mentioned in Q23) have its **nearest office**? ________ km

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ENUMERATOR'S COMMENTS

Remote sensing supporting national forest assessments

Barbara Koch[1]

THIS CHAPTER DISCUSSES THE FOLLOWING POINTS:

- Remote sensing methods for forest inventories.
- The framework conditions for use of remote sensing in NFAs.
- The application of new sensors such as Lidar and radar.
- Examples of practicable applications of remote sensing methods.

1. Introduction

This chapter concerns the integration of remote sensing data in national forest inventories. It provides a basic explanation of how remote sensing can be integrated into assessments and highlights key aspects. It presents an overview of different remote sensing systems and data types, including advantages and disadvantages, as well as future developments.

Remote sensing data are a longstanding element of forest inventories. The forestry sector was the first, after the military, to understand the potential of remote sensing data in support of inventory tasks. The definition of remote sensing, here, includes all airborne and space-borne instruments for Earth observation, from analogue aerial photography to space-borne digital instruments such as synthetic aperture radar (SAR) and opto-electronic systems. Not included in this definition are satellite-positioning or navigation systems, and terrestrial remote sensing systems such as terrestrial photogrammetry or terrestrial laser scanning. Navigation or positioning systems, as well as terrestrial remote sensing systems, are of increasing importance for sampling and sample-based field measurements, and should not be neglected in discussion of remote sensing for NFAs. However, this is not what most people refer to when talking about remote sensing, and it will not be included in this chapter.

2. Background and objectives

The use of remote sensing data in NFAs is complementary to sample-based field measurements and should be integrated in sample-based terrestrial designs. The reasons for integrating remote sensing data into NFAs are manifold. The main arguments are:

- Full coverage of the area in a relatively short time
- Lower costs due to reduced sampling intensity (some satellite data are freely available)

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- Visual documentation of the situation and any changes
- Generation of map data
- Accessibility of information from inaccessible or "difficult to access" terrestrial areas
- Increase of national capacity in mapping, monitoring and reporting
- More harmonized information assessment for the whole country
- Retrospective assessment of changes (the changing situation up to the present day).

The above advantages have promoted the integration of remote sensing information in NFAs. However, there are also a number of disadvantages, which still prevent comprehensive integration of remote sensing data in NFAs and forest inventories in general. In Europe, aerial photography is widely used for NFAs. In countries outside Europe the integration of satellite data is more common if NFAs are carried out. This is due to the often very large areas to be covered and the high logistical barriers for airborne data. The main obstacles to integrate, in particular, space-borne remote sensing data are:

- Data availability (are the data obtainable and, if so, from where?)
- Weather conditions
- Long-term perspective for space-borne systems (will data be available over longer time periods?)
- Problems of clear assignment of areas with/without trees to forest, according to the respective definitions
- Additional costs if existing terrestrial sampling design is retained
- Limitations on deriving the traditional set of forest parameters from airborne and space-borne data
- Missing technical capacity
- Flight permission for airborne data take

Taking into consideration the technological developments of the last 20 years and the increasing number of Earth observation satellites in orbit, it can be assumed that remote sensing data beyond aerial photography will have increasing relevance for NFAs. A number of countries have already integrated space-borne remote sensing data into their NFAs. The Global Forest Resource Assessment (FRA), produced by FAO (2010), now has a fully integrated remote-sensing component. Following tests on the integration of space-borne remote sensing into former FRAs with a focus on tropical forests, FAO noted that: "Satellite data enable consistent information to be collected globally, which can be analysed in the same way for different points in time to derive better estimates of change. Remote sensing does not replace the need for good field data but combining both provides better results than either method alone" (FAO, 2010: 340). This has led to global integration of space-borne data for forest area and forest area change estimations.

A key driver for use of information from satellite or airborne remote sensing data is the accessibility of remote sensing images via Google Maps. This triggers the use of remote sensing-based information, even though Google Maps allow the use of images for visual interpretation but not image processing for automatic information production (e.g. automatic classification of forest types).

The objective of this chapter is to provide information on the integration of remote sensing data into NFAs, examine the general structural requirements, and explore the kinds of data and methods available for use.

3. Structural requirements to integrate remote sensing data into NFAs

Before any decision can be taken regarding how to integrate remote sensing data (and what kind) into NFAs, it is important to identify the information to be derived from the data, and the kind of product and information to be delivered at the end. The identification of the forest parameters and the identified output largely define the inventory design and the data needed. If the forest parameters are derived

based on multiphase inventories, then the sample design has to be considered carefully. For example, if sampling is carried out with remote sensing data (e.g. very high resolution satellite data) and the resultant information needs to be calibrated with terrestrial sampling data, then an overlay between terrestrial plots and satellite samples is necessary.

In all forest inventories that use remote sensing data, the information derived concerns principally the forest area and forest area change estimations. This seemingly simple request includes a number of considerations and decisions. The first decision relates to the final product. Should it be presented in the form of wall-to-wall mapping, a sample-based approach or a combination of both? In many cases, a combined approach is the best solution, with full coverage comprising either medium or high-resolution data, such as Modis (Moderate Resolution Imaging Spectroradiometer) data with 0.5 km to 1 km spatial resolution, as used in FRA 2010, or high-resolution data such as Landsat TM (Landsat Thematic Mapper), as integrated into the NFA for Finland. The choice between using medium or high-resolution data depends mainly on the area to be covered, the budget available, the required scale and any other information requirements of the data. Based on full coverage data, a forest mask or a land-use map combined with a forest mask is produced. Although Modis and Landsat TM data are often used for full coverage mapping, a number of other satellites can be used for this task. One main factor in the selection of sensor type is the lifespan of the satellite sensor. Table 1 shows a selection of satellite sensors for forest monitoring.

Table 1

Suitability of selected satellite sensors for forest monitoring (*source:* Ridder 2007)

Image type	Free / low cost	No copy right	Optimised for vegetation	Length of repeat cycle	Available time range	Future sensor continuation
Optical, 5 to 50 m pixel resolution						
ASTER	+	-	+	- (16 days)	2000 onwards	unclear
CBERS CCD + IR-MSS	?	?	+	- (26 days)	2000 onwards	expected
DMC	-	-	+	+ (near daily)	2005 onwards	unclear
IRS LISS	-	-	+	- (5-24 days)	1997 onwards	expected
Landsat MSS	+	+	+	- (16 days)	1972-1984	N/A
Landsat TM & ETM+	+	+	+	- (16 days)	1984 onwards, since 05/2003 SLC off	LDCM
RapidEye	-	-	+	+ (daily)	2007	unclear
SPOT HRV	-	-	+	- (26 days)	?	expected
Optical, 150 to 1000 m pixel resolution						
CBERS WFI	?	?	+	+ (3-5 days)	2000 onwards	expected
IRS WIFS	-	-	+	- (24 days)	1997 onwards	expected
MERIS	?	?	+	+ (daily)	2000 onwards	expected
MODIS	+	+	+	+ (daily)	2000 onwards	VIIRS
SPOT VEGETATION	+	-	+	+ (daily)	1998 onwards	Vegetation 2
SAR						
ERS	-	-	-			
JERS	+	-	+			
RADARSAT	-	-	-			
ENVISAT	-	-	-			
TerraSAR-X	-	-	+/-		To be launched in 2007	unclear
ALOS PALSAR	-	-	+		2006 onwards	unclear

More and updated information can be extracted from the EO portal. The portal also provides information on upcoming satellite missions. One good example is the Sentinel 2 mission launched by the European Space Agency (ESA), which will provide wide swath high-resolution twin satellites, and has been designed to have a long lifespan. Brazil and China are also expected to provide long life satellites, in addition to India and the United States. Another important aspect when planning the structure for the integration of remote sensing into NFAs is the repetition rate of different types of sensors. This is especially important for countries with unfavourable weather conditions. Calculations or approximations on the probability of obtaining cloud-free scenes should be carried out, or a catalogue with existing data should be analysed before taking a decision on sensor type, as this issue can be critical if data are needed for a certain time period. Figure 1 gives an example of the probability of mean cloud fraction in Landsat ETM (Landsat Enhanced Thematic Mapper) acquisitions.

In the future, the sensor types used successfully in NFAs will be those that provide fairly high repetition rates. This is the case with Sentinel 2, which is designed to revisit every five days. According to a study (source unknown) based on Landsat TM data that simulates a 5.5 day revisit, the chances, globally, for cloud-free scenes would increase on average by around 30 percent compared with the 16-day revisits used at present. With a high revisit of five days, only a few tropical and sub-boreal forested regions would still encounter difficulties in acquiring cloud-free scenes within a reasonable time. For those areas, alternatives such as SAR sensors or optical sensors with daily repetition will be needed. The time of the year also has an influence on the probability of getting a cloud-free scene. In general, in many regions it is more difficult to get cloud-free scenes during the summer and winter periods than in spring or autumn.

The use of airborne remote sensing complements space-borne remote sensing. Its application for NFAs is mainly a question of cost and practicability. In many countries, the integration of airborne data fails due to restrictions on obtaining flight permission. In addition, country size may render full coverage by airborne systems impossible. Even in the context of a multiphase inventory, sampling with airborne data is a logistical challenge.

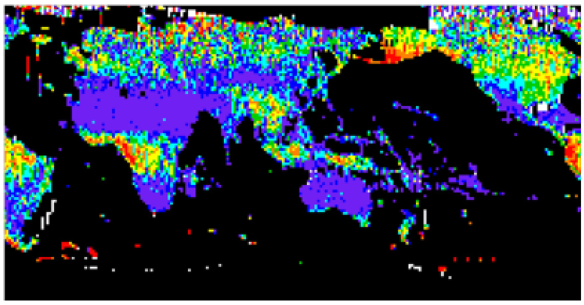


Figure 1: Mean cloud fraction in ETM acquisitions for each global land scenes in 2002

Note: 0<purple<0.2, 0.2=<dark blue<0.3, 0.3=<light blue<0.4, 0.4=<green<0.5, 0.5=<yellow<0.6, 0.6=<orange<0.7, 0.7=<red<1.0.

Source: Roy and Ju, 2007.

After having considered the aforementioned general conditions, the set of eligible sensors has to be analysed according to four major characteristics in order to best fit the information and mapping requirements. The selection of eligible sensors can be best done together with companies that sell data and the requested information products. However, knowledge on the part of the customer concerning the quality of different satellite data, and the type of possible information, will give a decided advantage. The four major characteristics that define image quality are as follows:

1. Spatial resolution defines the ability of a

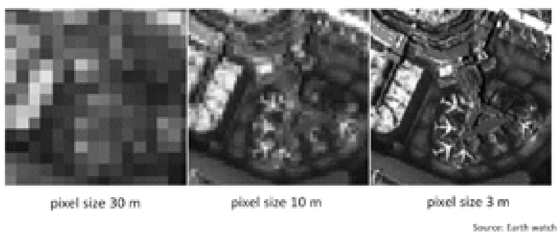


Figure 2: Examples of images with different pixel sizes

Source: Earth watch.

sensor to identify the smallest size detail of a pattern on an image

2. Radiometric resolution defines the ability to detect differences in the reflected energy. For example, if there are two paved flat areas that differ only slightly in grey colour, there will be no difference between the two areas for a black and white image of a sensor with low radiometric resolution, while there

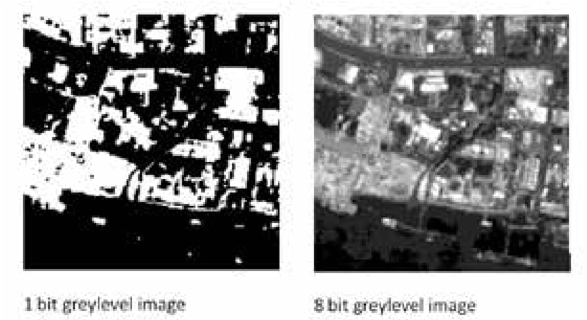


Figure 3: 1-bit and 8-bit radiometric resolution

Note: Radiometric resolution smaller than 8-bit is considered low radiometric resolution, 8-bit is medium radiometric resolution, and 12-bit and higher is considered high radiometric resolution.

Source: unknown.

will be a difference for a black and white image of a sensor with high radiometric resolution.

3. Spectral resolution is the sensitivity of a sensor to respond to a specific frequency range; in other words, the number of different spectral regions in which the reflected energy can be measured. For example, for a colour composite the

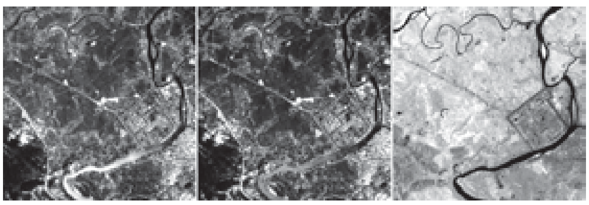


Figure 4: The different spectral channels of Landsat TM (B2 to B4)

sensor has to have the ability to measure the reflected energy in at least three different spectral regions (channels).

4. Temporal resolution defines the repetition rate of the satellite. It determines the time sequence in which the satellite will collect data over the same area (e.g. daily, weekly, monthly).

4. Optical sensor systems

The integration of remote sensing-based data into NFAs mainly relates to optical systems. There is a long tradition of aerial photography as a supporting information source in NFAs, as well as in commercial inventories. According to the aforementioned major characteristics, aerial photographs have a very high spatial resolution, a high radiometric resolution, and the spectral sensitivity is over the visible to the near-infrared range of the electromagnetic spectrum (400 nm to 1100 nm). While in the past analogue systems with film material were used, today there is an increasing preference for digital airborne cameras with normally four spectral bands – three in the visible and one in the near-infrared range. A temporal resolution is not applicable for aerial photographs because the flight time is more or less freely selectable. The probability of obtaining cloud-free data from aerial photography is therefore higher than from satellite-based optical systems, due to the high flexibility of date take.

In Europe, in particular, aerial photography still plays a prominent role within forest inventories. In a number of countries, forest/non-forest decisions and change in forest area are based on aerial photographs. The intensive use of aerial photography in Europe is the result of a mix of factors, including the long tradition of usage, the high spatial resolution, the often strong interrelation between the survey institutes that produce the aerial photographs and forest administration, the relatively high costs for very high resolution satellite data (very high resolution satellite data can still not compete with the costs of aerial photographs), and the higher probability of obtaining cloud-free data for the envisaged area within a certain time. Other factors that facilitate the use of aerial photography in

Europe are the relative ease of obtaining flight permission and the relatively smaller mapping units compared with other areas such as South America and the United States.

The new generation of digital aerial photography will probably further advance the complementary use of aerial photographs along with terrestrial measurements, due to better radiometric and spectral characteristics and the increased possibilities in data processing. Investigations by Hoffmann (2010), based on digital infrared aerial photographs, highlighted the possibility of assessing important forest parameters such as major tree types, gaps and damage. The potential information from stereo aerial photographs, tree height, is normally not used to derive further forest properties, such as wood volume or above-ground biomass estimations. In a number of countries, aerial photographs are the only type of remote sensing data used within an NFA. One notable use of aerial photographs within NFAs is to reduce the number of terrestrial samples plots without loss of information and accuracy (e.g. Switzerland).

Outside of Europe, but also in some countries within Europe, optical satellite data are often used as complementary data source for NFAs. In general, not very high resolution satellite data are used but high-resolution satellites like Landsat TM. The most used satellites in NFAs by far are Landsat satellites. This is due mainly to the low or none-existent data costs and the long life span of the Landsat series. In general, satellite data are used for wall-to-wall mapping, as in the case of the Finnish inventory, but also for sample-based mapping. In terms of the four sensor characteristics that need to be analysed before deciding on a sensor type, the most problematic requirement is the temporal resolution of the available satellites, while spatial, radiometric and spectral resolution are for a number of satellites (e.g. Landsat TM, Spot, IRS) suitable for forest inventories. Temporal resolution is critical especially for forest inventories, because the forest is often located in areas with relatively high cloud coverage. An internal study by the DLR, Germany, showed that, on average, it takes five years to fully cover Germany with cloud-free Landsat TM scenes. Therefore, a major consideration is to ensure sufficient temporal resolution, which will improve data availability. Costs also have a strong influence on the use of remote sensing data in NFAs.

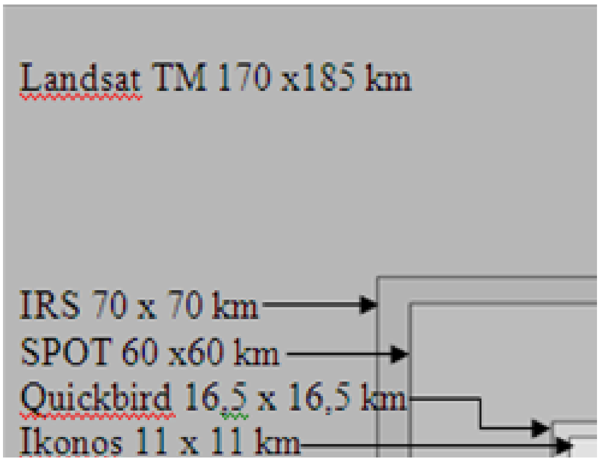


Figure 5: Coverage areas of different sensors

The higher the resolution, the more difficult it is to obtain full coverage of a large area, and the more costly it will be. Figure 5 shows coverage for different sensors scenes.

Wall-to-wall mapping with very high resolution satellites is not feasible in an NFA due to the costs and difficulties in obtaining full coverage within a reasonable timeframe. Wall-to-wall mapping, however, is useful for any kind of stratification and for forest/non-forest decisions (Öhmichen, 2007). Investigations by McRoberts *et al.* (2002) and Dees and Koch (1997) show that stratification of the forest area based on optical satellite data improves either the accuracy of the estimates or allows a reduction of sample plots without loss of accuracy. If stratification is applied there are two approaches: pre-stratification or post-stratification. While pre-stratification will have an influence on the sample plot design, post-stratification allows the existing sample plot design to be kept.

In many cases, the integration of remote sensing data is based on a multiphase approach. In this case, for example, forest/non-forest

classification is based on medium-resolution data, while in a second phase high-resolution satellite data, very high resolution satellite data or aerial photographs are sampled. For the sampling, the data used vary from high-resolution to very high resolution satellite data or aerial photography. The selection of data type is mainly dependent on the forest parameters, which are derived from the remote sensing data. If forest condition, tree species or forest structure are to be mapped, then aerial photography or satellite data with very high spatial, spectral and radiometric resolution are needed.

A number of investigations have been carried out to estimate wood volume and above-ground biomass from optical data-based regressions. There are correlations between the reflected signal and wood volume, as well as above-ground biomass in the near-infrared spectrum, short-wave infrared and for some indices. However, the variance is very high and the higher the wood volume and above-ground biomass of a forest, the lower the correlation. Nevertheless, remote sensing data will be of significance in the future, especially for modelling of CO_2 sequestration, as remote sensing is the only tool that can provide information on forest conditions and forest area at a global level. The Global Observation for Forest and Land Cover Dynamics Sourcebook presents the first outlines on how optical satellite data can be used for the modelling of CO_2 binding (GOFC-Gold, 2009: 108) .

In the future, biodiversity information will also gain importance in NFAs. If biodiversity is to be mapped, two different biodiversity types need to be considered: structural biodiversity and species diversity. Remote sensing can provide information on both categories at the landscape level. The identification of species in remote sensing data is limited to tree species or forest types. While tree species identification is mostly based on near-infrared aerial photographs, the identification of forest types can be carried out with very high or high-resolution multispectral satellite data. However, it should be noted that identification is limited, regardless of the use of aerial photographs or satellite data. Aside from the spectral similarity of some tree species, the limitations are linked to the age of the trees (a tree can change its spectral properties drastically over age), the mixture pattern of tree species and the condition of trees. This is the reason why forest type identification is often not possible in tropical and subtropical areas, characterized by a tight mixture of different tree species. In addition, the exposure of forest areas can vary, thus increasing the problem of species or forest type identification based on reflectance values. The problem of reflectance differences due to different exposure towards the sun cannot be fully removed by any correction algorithm. Nevertheless, with good processing, reasonable results can be achieved.

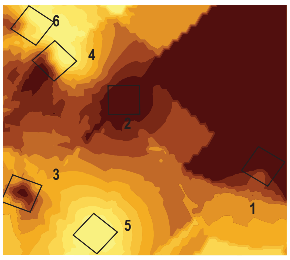
Investigations linked to the availability of hyperspectral data show that forest type and species recognition can be improved. In general, structural diversity is better accessed by remote sensing data. In particular, horizontal structural diversity can be mapped

Figure 6: Segmentation of forest area based on an IRS-1D and Landsat TM fused image

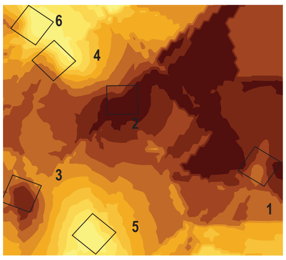
Source: Ivits *et al.*, 2004.

quite well, and even better than with terrestrial measurements. The quality of the result is mainly influenced by the availability of a good match between the spatial resolution and the requested mapping scale for the structures (Figure 6).

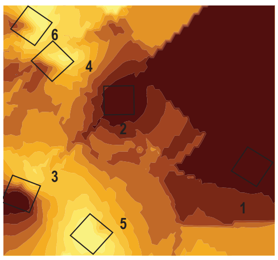
Investigations at FeLis showed that, based on structural and forest type information extracted from Landsat TM and IRS-1D (Indian Remote Sensing Satellite) data, it is possible to model habitat structures for bird species. Based on grey values and grey value-derived indices from Landsat TM and IRS-1D, a high significance was shown by a goodness-of-fit test (Hosmer and Lemeshow, 2000) for a corresponding final logistic model predicting the absence and presence of certain bird species (C=4.2610, P > Chi-Sq=0.8328) (Herrera, 2003). This indicates that, for certain bird species, presence and absence is strongly correlated with the grey value-derived co-variables, which are included in the model. The c statistic indicates that 92.9 percent of the probability of bird species occurrence is determined by the listed co-variables.



Ordinary Kriging surface calculated from observed values



Ordinary Kriging surface of values predicted from grey values



Ordinary Kriging surface of values predicted from patch indices

Figure 7: Example of spatial ordinary Kriging surface of logistic regression results

Note: Observed data and predicted values from grey values and patch indices of the Quickbird image were input to the model. Darker surfaces indicate a high probability of presence, while brighter surfaces indicate a high probability of species absence.

Investigations by Ivits *et al.* (2004) also showed that patch indices and grey values achieved similar results in predicting the presence of certain bird species. Logistic regression denoted strong predictive power of the remote sensing variables (Figure 7). It seems that remote sensing indices can be very useful indicators of bird species diversity when bird species are handled separately, while it is less effective in the case of groups of species.

5. SAR and laser scanner data

5.1 SAR data

While it can be assumed that optical remote sensing data will be of increasing importance for NFAs in the future, applications of SAR data will probably remain limited. This is due to the high complexity of radar data processing and the limitations they have in mountainous areas. The main advantage of radar data is their transmission through clouds, which makes the data fairly weather independent. With L-band data the forest/non-forest decision, and therefore the changes in forest cover, can be assessed quite well (Häme *et al.*, 2009), even with automatic classification procedures. Also in C-band and X-band data, image interpretation of forest areas is possible (Figure 8).

Figure 8: Colour-coded TerraSAR image north of Munich

Note: The data were taken on 26 June and 7 July 2007, 5:26 UTC, resolution: 3 m, mode: Stripmap, polarization: VV und HH.

Source: DLR, Germany.

Nevertheless, there are strong limitations in mountainous areas due to the radiometrical and geometrical problems that occur in the data. Even though there are a number of correction algorithms, the radar shadow and the differences in backscatter intensity due to incidence angle cannot fully be corrected. This limits the use of radar data in NFAs, even for forest/non-forest decisions. The extraction of forests parameters from radar data is also difficult and results are not consistent. Algorithms and models do exist but largely at the research level, and their integration into NFAs is not practical. A lot of work has been carried out on the use of radar data for above-ground biomass assessment (Koch, 2010); however, the studies are not based on robust tests and only apply to the specific forest and data take situation. The assessment of above-ground biomass with radar data is restricted by saturation, which is relevant for forest areas with high-wood volume or high above-ground biomass. Nevertheless, in forest areas with low above-ground biomass, such as boreal or sub-boreal regions, reliable measurements are possible.

In general, radar data can be quite valid for integration into NFAs if certain environmental conditions are fulfilled: flat to hilly area and relatively low above-ground biomass and wood volume. Some new investigations indicate that the saturation problem can be minimized; however, this is still solely a matter of research. Nga (2010: 79) writes that L-band and P-band data with cross polarization are most sensitive to above-ground biomass, as previously stated by LeToan *et al.* (1992) and Ketterings *et al.* (1999). In particular, cross-polarized P-band could contribute substantially to the modelling of above-ground biomass (Henderson and Lewis, 1998). This is due to the fact that cross-polarized backscattering in the L and P-band is related to volume scattering, which is correlated with above-ground biomass. The problem of saturation can be reduced with longer wavelengths, but according to Nga (2010) remains a problem for forests where the above-ground biomass is over 200–250 Mg/ha. The identification of tree species or forest types is, to the best of knowledge, not possible. Even the separation of broadleaf and conifer forests is not very reliable. Taking into consideration the existing limitations and the complexity of radar data processing, as well as the lack of long Earth observation radar satellites for the L and P-band, the integration of radar data into NFAs seems to pose difficulties. The use of airborne systems is possible, but remains quite expensive, and not enough commercial providers offer these data to integrate airborne radar data into NFAs.

5.2 Laser data

The use of laser data within forest inventories has increased in recent years. Most projects are still at the research stage, but could prove to be of high value for practical applications in forest inventories (Naesset, 2004; McRoberts, Tomppo and Naesset, 2010). The use of airborne laser (ALS) data for forest applications is probably the most innovative development in remote sensing for forest inventories within the last ten years. The enormous potential of ALS data is based primarily on the possibility to model the forest surface and the forest ground from one dataset. In addition, it is possible to assess vertical forest structures.

The extraction of accurate height information over forests allows the modelling of several important forest parameters. Height is nearly adequate to dbh as an input variable for modelling important forest parameters such as wood volume and above-ground biomass. dbh and dbh distribution, information crucial for forest managers, can also be assessed from height. There are two approaches to modelling forest parameters. The first is an area-based approach, which can work with low-density data (Figure 9); the second is the single tree-based approach, which needs high-density data with 8 to 10 points per square metre to achieve good results. Many investigations have been carried out on this topic and Hyyppä *et al.* (2009) give a comprehensive overview of the status of ALS data in forest inventories.

Area-based approaches can be performed

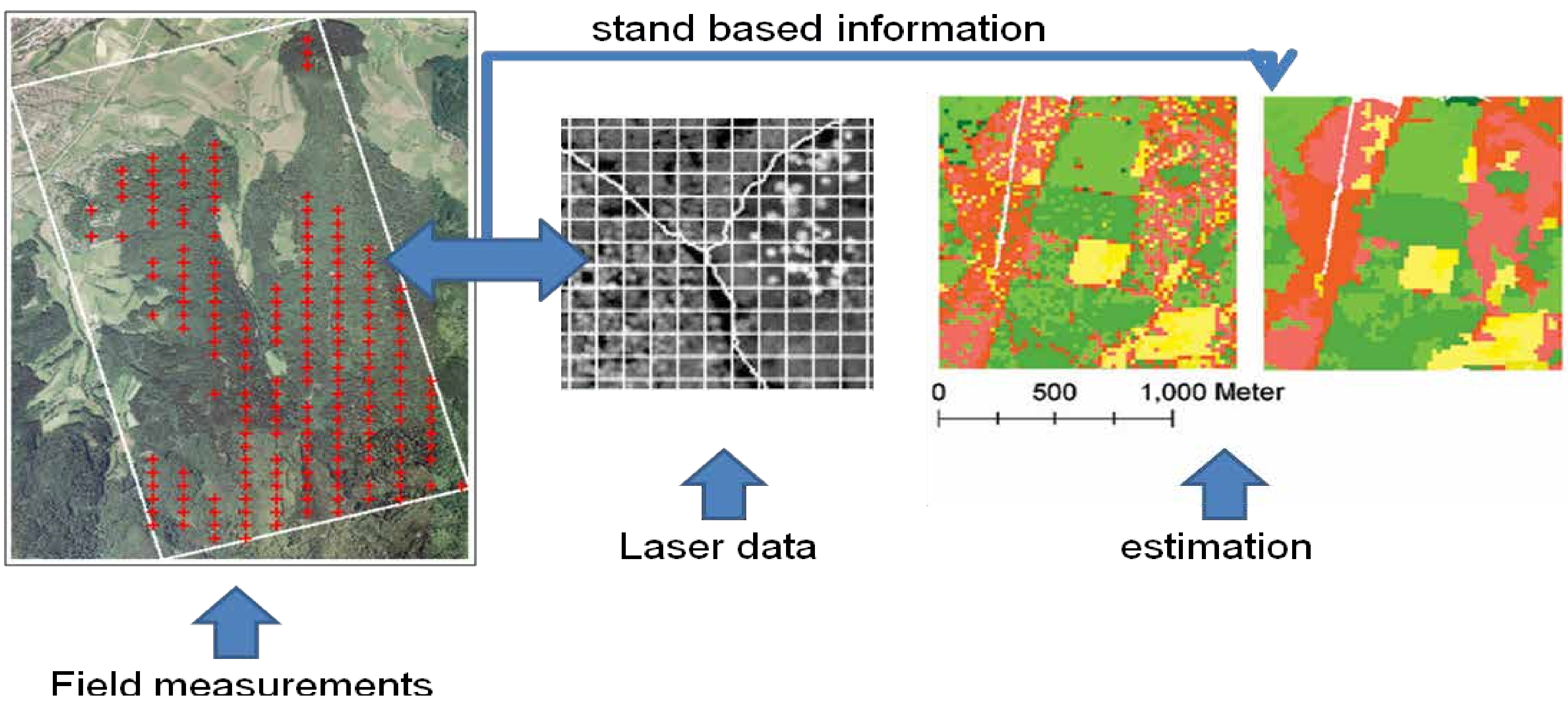


Figure 9: Schema for an area-based approach to estimate forest parameters

Table 2: Plot level RMSE, RMSE% and Bias% for CIR Images, Landast TM and LiDar data for standing timber volume and above ground biomass across different imputation methods (source: Latifi et al 2010)

	CIR image			TM image			LiDAR data		
	RMSE	RMSE%	Bias%	RMSE	RMSE%	Bias%	RMSE	RMSE%	Bias%
Euclidean distance									
Volume	154.31	58.65	1.93	142.73	54.25	−2.91	119.61	45.46	0.75
Biomass	95.49	56.92	1.79	88.43	52.71	−2.80	74.46	44.38	0.30
Mahalanobis distance									
Volume	145.76	55.40	2.65	158.74	60.33	1.68	127.55	48.48	2.42
Biomass	89.15	53.14	2.28	97.37	58.04	1.71	79.60	47.45	2.56
MSN									
Volume	145.54	55.32	0.57	148.40	56.4	−0.33	98.411	37.40	0.72
Biomass	92.55	55.16	2.09	90.68	54.05	−3.39	61.59	36.71	1.94
RF									
Volume	109.21	41.51	−1.84	117.12	44.51	−1.48	54.438	23.97	−1.97
Biomass	65.01	38.75	−3.16	69.90	41.66	−3.31	37.32	22.24	−2.44

as a regression analysis, k-NN (k-Nearest Neighbour classifier) analysis or yield table method. This is described in detail by Straub, Weinacker and Koch (2009). Investigations by Latifi, Nothdurft and Koch (2010) demonstrate that the use of laser-derived information is superior not only to Landsat TM data, but also to aerial photographs for important forest parameters such as wood volume and above-ground biomass (Table 2).

Aside from good estimations for wood volume and above-ground biomass, many other parameters of increasing relevance in NFAs, such as crown density or forest structure parameters as indicators for forest biodiversity, can be estimated with high quality using the area-based approach from laser data. The identification of tree species or forest types is of greater difficulty at present. While it is possible to use different methods to separate high-quality broadleaf from conifers, the further identification of tree species or forest types is not very practicable with laser data. Despite some successful investigations (Heinzel and Koch, 2011; Höfle *et al.*, 2008; Hollaus *et al.*, 2009; Vauhkonen *et al.*, 2010) using geometrical as well as physical information from airborne laser data for tree identification, the results are not yet equal to operational application in an NFA. In recent years the single-tree approach has gained more interest for forest inventories. Investigations have shown that the integration of sample-based single-tree information is needed especially in mature stands for better management, as well as harvest and nature protection planning. The single tree delineation is a challenge and the quality that can be achieved is dependent on the data quality, the forest types and the algorithms used. A comparison of algorithms in different stand types has been carried out by a group of researchers within the

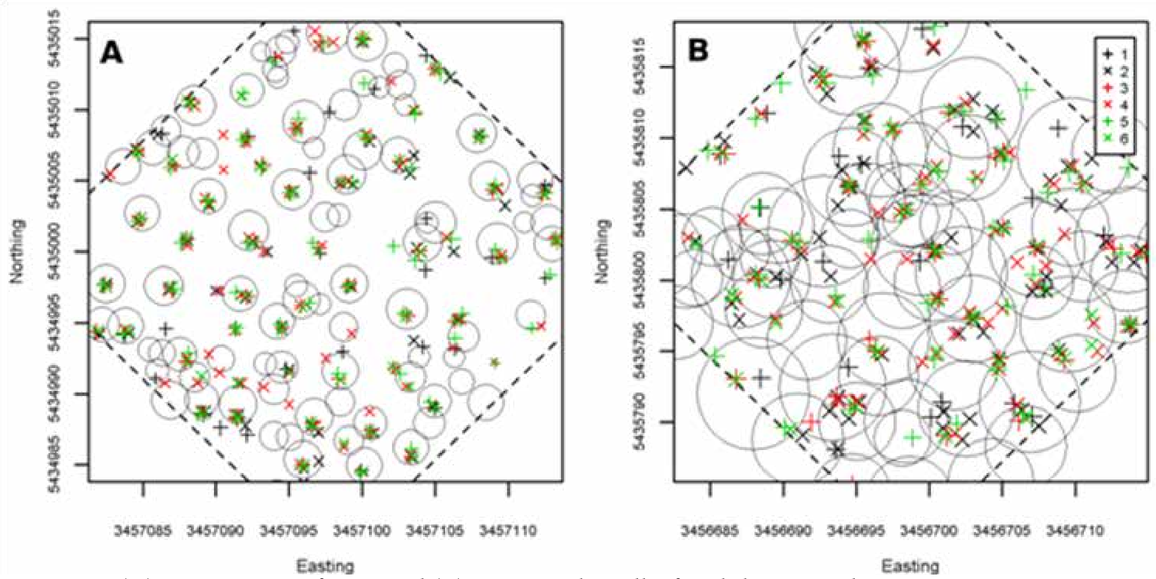


Figure 10: (A) Germany coniferous and (B) Germany broadleaf multilayer stand.

Note: Numbers 1 to 6 represent the different algorithms.

framework of the WoodWisdom project (Figure 10) (Vauhkonen *et al.*, 2010). While the performance of different algorithms was similar, with not much difference, the main problem was the kind of stand type. In coniferous stands the detection rate was much better than in broadleaf multilayer stands.

Laser data integration into NFAs is only possible within the framework of a multi-phase inventory on the basis of sample plots, due to the fact that lasers are normally operated from airborne platforms, which cannot be applied to wall-to-wall mapping covering large forest areas. The only satellite-based system, IceSat/Glas, is not operational and the data were useable only for research purpose. A planned satellite-based Lidar system will only be available in a few years. This limits the application of laser data mapping within NFAs.

However, within the framework of a multiphase inventory, laser data can give very valuable information on many forest parameters assessed during NFAs. The use of sample-based Lidar data will reduce the number of terrestrial sample plots and/or the accuracy. Compared with other remote sensing data, the information inherent in laser data is probably the highest in respect to a number of forest parameters. However, the data are still not standard and are more costly than aerial photography, which is a serious concern for the integration of Lidar data into NFAs. In many countries, the application of Lidar is also quite difficult due to missing commercial providers and flight restrictions. In addition, a major drawback is the poor information on tree species. More research is still needed for a multisensoral approach on one platform, such as laser-combined systems with a multi-spectral scanner or a multiwavelength Lidar system working at three different wavelengths. Better exploitation of the full-wave and physical information, such as intensity, still need to be investigated to allow further advances.

6. Information processing

The exploitation of information from remote sensing data can take quite different forms. In many applications the visual interpretation of images is the most practical way to extract the needed information. Within the FRA 2010 as well as the REDD initiative, image interpretation is used for the identification of the forest area and area change, as well as the degradation of forests. However, interpretation is cost intensive and subjective. The results depend largely on the training of the interpreters and are difficult to compare. Issues of subjectivity start with the classification of forest area, because the delineation of the forest boundary is not always obvious to the interpreter. However, it should be noted that terrestrial assessment is in many cases subjective.

Machine learning algorithms are preferred for classification, mainly for reasons of efficiency and to ensure better standardization of the process. The results are not necessarily more correct than those achieved through interpretation, but are more transparent. A number of different classifiers are well known through use over many years: **Minimum Distance, Maximum Likelihood** and **Artificial Neural Network**. The simplest method is Minimum Distance which, based on the mean of the training classes, calculates the shortest spectral vector distances in the multidimensional space. The Maximum Likelihood, based on the mean vectors and co-variances of the training classes, calculates the statistical (Bayesian) probability that a pixel belongs to a class. For this a Gaussian distribution is assumed and an equiprobability formed for each class (NASA, 2010). However, the assumption of the Gaussian distribution of the grey values often does not meet with reality. Artificial Neural Networks are not much used for practical purposes, mainly because the classifier is computing intensive and has not yet proved its superiority. Artificial neural network algorithms image the neural structure

of the brain. They start with a set of input data and learn by comparing the classifications with the known actual classification. The results are fed back into the network, and used to modify the network algorithm for as many iterations as are needed (Zhang *et al.*, 2000).

In the 1990s, **object-oriented classification** algorithms (Lillesand, Kiefer and Chipman, 2008) gained ground. Here, the classification is a two-step approach. The first step involves segmentation (grouping together adjacent pixels into segments or regions according to similarity criteria) based on reflectance properties (colour), texture and shape. Pattern and context can also be taken into consideration. The process is a form of a hierarchical classification; therefore, each class can be described in terms of its optimal scale. In the second step the segments are classified. In many cases, the **Nearest Neighbour** classifier is used (McRoberts, 2012), which is similar to the Minimum Distance classifier, and is based on multi-dimensional spectral distances. Another option is the **Fuzzy classifier**, which tries to take into consideration the problem of mixed pixels. For each pixel a membership function is calculated and the probability of belonging to one or the other class is provided (Nedeljkovic, 2004).

The most prominent software for object-oriented classification today is eCognition. Two relatively new additions are the **support vector machine** and **random forest** classifiers. Good classification results are achieved in land use and forest classifications with both classifiers.

Support vector machines (SVMs) proved able to handle high feature spaces and complex class discriminations better than other methods (Heinzel, Ronneberger and Koch, 2010; Mountrakis, Im and Ogole, 2011). The SVM classification is a supervised non-parametric statistical learning technique, which does not require an assumption of the underlying data distribution. This is the major advantage of this classifier. The SVM is always related to a two-class separation in a multidimensional feature space. Multiclass separations are possible by breaking them down into two class problems, which are combined in certain ways. The SVM classifier aims to use an iterative process to find a hyperplane in which the misclassification is minimized using the training examples.

The Random Forest classification is based on many individual decision trees. It is a supervised learning algorithm that can handle a large number of attributes and runs efficiently on large datasets. Independent of the number of input variables and runs the classifier is not overfitting. It has produced high accuracies in many classifications (Klassen and Paturi, 2010). Latifi *et al.* (2010) also found that the Random Forest classifier performs better than the SVM classification for classification of forest attributes. The advantage of the classifier is that an evaluation of the classifications is performed during the processing. The Random Forest classifier takes "bootstraps", which are samples of the training dataset. Parallel classification trees are generated and at each node a random sample of variables is selected. The best split is carried out and the tree grows to the largest extent possible. The tree with the lowest error rate is then selected as the strongest classifier.

Besides the classifiers presented above, the **k-Nearest Neighbour (k-NN)** non-parametric estimator is a very efficient method to use remote sensing data in combination with sample plots, in order to get full coverage information. The k-NN method has performed well in the NFA in Finland (Tomppo, 2002). The method is based on the regression between spectral characteristics of image pixels over areas with field measurements and image pixels with no field information. Based on Mahalnobis or Euclidean distance measures of k numbers of Nearest Neighbours, the pixels with no field information will assume the field information of those pixels which have an underlying field information and match best. In this way, the information from the field measurements is transferred to the areas with no field information. In the field of forestry, a large number of investigations with

different kind of sensors have been carried out using the k-NN method. It has proved its usefulness, however the type of sensor data and forest type will significantly influence the results (Latifi *et al.*, 2011).

7. Concluding remarks

This chapter does not attempt to provide a complete picture of the use of remote sensing in national forest inventories. Instead, the intention is to provide a condensed overview of certain key aspects. No information is provided on sampling design as this is covered by other authors with more specific experience in this field. For a deeper examination of the remote sensing topic a list of references is provided below.

Self-study exercises

1. What support can satellite data typically provide for NFAs?
2. How can remote sensing be used in a multiphase inventory?
3. Why is it difficult to work with remote sensing in northern or tropical countries and what possible solutions do you see?
4. Why is radar data more difficult to use than optical?
5. What are the limits for satellite data in terms of daily repetition rates?
6. Why are high-resolution satellite data in NFAs often sampled?
7. Why might it be necessary to adapt the sampling from remote sensing to the field sampling design?
8. Is it possible to use satellite images in NFAs without computers?
9. Is any pre-processing necessary before starting to use satellite images within an NFA?
10. Who can do the geocoding?

Glossary

ALS	airborne laser scanner
CIR	colour infrared
dbh	breast height diameter
ESA	European Space Agency
FAO	Food and Agriculture Organization of the United Nations
FRA	Forest Resources Assessment
GOFC-Gold	Global Observation for Forest and Land Cover Dynamics
IRS 1D	Indian Remote Sensing Satellite
k-NN	k Nearest Neighbour classifier
Landsat ETM	Landsat Enhanced Thematic Mapper
Landsat TM	Landsat Thematic Mapper
Modis	Moderate Resolution Imaging Spectroradiometer
NFA	national forest assessment
REDD	Reducing Emissions from Deforestation and Forest Degradation in Developing Countries Programme
RMSE	root mean square error
SAR	synthetic aperture radar
SVM	support vector machine

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Information management and data registration

Alan J. Thomson

THIS CHAPTER DISCUSSES THE FOLLOWING POINTS:

- Information management including collection, quality control, archival and accessibility of collected data and associated metadata.
- The distinction between data, information, knowledge and wisdom.
- The high failure rate among software projects, and factors and theories contributing to success.
- The "knowledge ecosystem" approach: a complex system of people, institutions, organizations, technologies and processes in which knowledge is created, interpreted, distributed, absorbed, translated and utilized.

Abstract

Information management involves the collection, quality control, archival and long-term accessibility of collected data and associated metadata. Information provision and reporting requirements of international agreements add additional challenges. National-level database structures are often incompatible with each other, and information can be outdated, partial or subjective, with precision and accuracy of data being unknown. This chapter discusses the interacting roles of data models, data registration, standards, harmonization, metadata, adjustment factors, distributed systems and interoperability in addressing such issues. It also highlights the high failure rate among software projects and discusses factors contributing to improved success.

Rapid development of the internet, and particularly the World Wide Web, have radically changed information management for forest resource assessments in two major areas: (i) distributed information management, and (ii) responses to remote requests (in the form of searches) for information. Demand for forest information has also changed, reflecting a shift in perspective in forest policy from timber production towards an emphasis on social, economic and environmental issues. There is a growing need for data on forms of forest change, such as deforestation, forest degradation and forest plantations, each of which may have its own information requirements.

The information provided by a forest information system varies according to the purpose and scale for which it is used. Information employed at the strategic and integrative level has to be aggregated in both thematic and spatial terms. However, forest resource assessments are often based on a form of synthesis dependent on partial data

plus expert opinion.

Information management is crucial to meeting national and international reporting requirements. Cost and timeliness are important factors, thus consideration of funding and financial mechanisms is essential to success. While information is the principal output of a forest resource assessment, knowledge plays a key role in the process of collecting data and transforming it into information. In particular, where stakeholder participation is involved, the NFA process is a complex and many-faceted system comprising people, institutions, organizations, technologies and processes, in which knowledge is created, interpreted, distributed, absorbed, translated and utilized: it is therefore discussed in the context of knowledge ecosystems.

1. Introduction

1.1 What is information management?

A national forest resource assessment has been defined as a national process that collects, manages, makes available and analyses information on forest resources, their management and use, covering an entire country. It also includes analyses, evaluations and scenario development for use in policy processes (Anon, 2002).

Information management includes the collection, quality control, archival and long-term accessibility of collected data and associated metadata. It emphasizes the timely and general availability of this information and seeks to ensure its long-term preservation, and can include both source information and derived information. A distinction is made between data, information, knowledge and wisdom (DIKW); while there are many definitions, there is a consensus that they should be defined in terms of one another (Rowley, 2007).

Data are unprocessed facts or observations, which may or may not be meaningful in themselves. Information consists of assemblages of data which, taken together, can provide answers to "who?", "what?", "where?" and "when?" questions. Knowledge is "know-how" and makes possible the transformation of information into instructions (Ackoff, 1989). Knowledge is therefore a product of information and human interpretation, and encompasses the context in which observations were made and their inter-relationship with other activities. It also embodies the recognition of patterns within data and information, and the understanding of the implications of these patterns. Wisdom allows application of knowledge to new situations and enables foresight. While the main output of a forest resource assessment is information, knowledge plays a key role in the process of collecting data and transforming it into information.

Human input increases at higher levels of the DIKW hierarchy, while computer inputs decrease (Pearlson and Saunders, 2004). However, global change has constrained reliance on the experience and wisdom of forest managers (FAO, 2010b). In fact, "despite being at the top of the DIKW hierarchy, wisdom is a neglected concept in the knowledge management and information systems literature. If the purpose of information systems and knowledge management initiatives is to provide a basis for appropriate individual and organizational actions and behaviour more researchers and practitioners need to engage with the debate about the nature of individual and organizational wisdom" (Rowley, 2007). In particular, the information systems and knowledge management initiatives associated with an NFA should be considered in this light.

The failure rate of software development projects is high, and in developing countries most projects result in total or partial failure (Heeks, 2002). Success is more likely when the issues discussed in this chapter are addressed during the design process, taking account of users' capabilities, work patterns and viewpoints.

1.2 National and international requirements for FRAs

Support to NFAs is one of the main components of the FAO Forest Resource Assessment (FRA) programme and, among other issues, addresses the mounting complexity of demand for forest information. As information requirements now cover protective functions of forests, in addition to productive functions and socio-economic aspects of multiple purpose use (FAO, 2004), this provides challenges to information management, with NFAs now including consideration of topics such as poverty alleviation (McConnell and Thunberg, 2009), nutrition and gender issues. Information provision and reporting requirements of international agreements add additional challenges, with Australia listing 17 international forest-related agreements, forums or statements of relevance (Bureau of Rural Sciences, 1998: 110), as well as detailed regional agreements.

Ownership and management of forests by communities, individuals and private companies is on the rise. Forests are managed for a multitude of uses and values, and the management of forests for social and cultural functions is increasing, although this area is difficult to quantify (FAO, 2010a). Recent studies recommend increased stakeholder participation in NFAs and decision-making (Anon, 2009a; FAO 2010b; McConnell and Thunberg, 2009)

1.3 Current status of information management in NFAs

Countries vary widely in the availability of forest information and their information management capabilities (Anon, 2002; EC/FAO Partnership Programme, 2000; FAO, 1999a, 2001a; Saket, 2002). Availability is highly correlated with a country's level of development, and within any given country the various components of a forestry information system are typically at different stages of development. Even when data are available they are frequently difficult to access; moreover, their reliability is often questionable. As a result, data are often ignored and not used in any meaningful way. The different institutions involved are not always aware of each other's activities, and there is often considerable duplication of effort with conflicting data frequently reported for the same items. Different data components often have different coverage and time frames, thus requiring special processing, tabulations and adjustments.

Putting NFAs into a common framework is difficult, as national-level database structures are often incompatible with each other (FAO, 2001a: 17). In the Global FRA process, information was frequently found to be outdated, partial or subjective, and in most cases the precision and accuracy of data were unknown. In the 2010 FRA, the response rate was very good but poor information availability remained a problem, especially in developing countries, while data quality was also an issue. To address these issues, FAO developed a programme to support NFAs. Nevertheless, information gaps remain wide in many countries, including major forest countries (FAO, 2010a). An independent evaluation of FAO's role and work in statistics and information technology has been carried out (Dunmore and Karlsson, 2008).

2. A basic FRA scenario

2.1 Data

Production of information involves data collection, processing and reporting (FAO, 1999b). A IUFRO Task Force Report on Information Technology and the Forest Sector gives detailed coverage of ICT issues in the forest sector in general (Hetemaki and Nilsson, 2005). For the NFA process in particular, data collection processes are described in one of a number of relevant publications available

from the FAO FRA website (FAO, 2008). Inventory data can be analysed together with other information in order to investigate relationships between volume and other spatial and statistical variables, such as soils, slopes, bio-climatic indices, population density and so on. This approach can be used to fill data gaps for forest types for which no information is available (FAO, 1998).

2.1.1 Data models

A data model helps one to perceive, organize and describe data in a conceptual schema that includes both the data and the operations for manipulating the dataset (Tokola *et al.*, 1997). Data models for traditional measurement-based inventory data are well established, whereas studies of data models for the socio-economic aspects of forests, which may involve interview-based data, are much less available and may include fields such as question categories and interdependencies (Thomson, 2000). Data models can enable interoperability among organizations, avoiding syntactic conflicts, and facilitate sharing data with different granularity and detail (Hernández *et al.*, 2009). Compliance of proposed data models with requirements can be evaluated prior to implementation (Camerata and Pellegrino, 2010).

2.1.2 Data input

The use of data loggers has greatly enhanced the input and quality control of tree measurements, especially when linked to a central database via mobile communication and internet access (Kleinn, 2002). The database can be permanently updated and checking procedures adjusted immediately and uniformly for all field crews, which improves data quality (see section 2.1.4, p. 97). However, the most significant gain results from immediate digital storage of data in the field with periodic data transfer. Input of geospatial data by digitizing or image analysis is covered elsewhere in the knowledge reference.

Much of the information used in a NFA may reside in existing printed reports. Use of scanners and optical character recognition can facilitate the transfer of such reports into digital media. Audio recording followed by transcription into a word processor has traditionally been used to record interviews, but advances in speech technology now permit direct speech input to the word processor.

New devices are continually being developed, such as programmable identification devices (PIDs) and radio-frequency identification (RFID). Appropriate approaches for technology transfer from developed countries to developing countries must be developed, identifying opportunities for cooperation among organizations and relevant regional actors, although the technology level in many countries is still low, and the policy, institutional and social constraints to technology transfer are severe in these countries (Puustjärvi, Katila and Simula, 2003). However, technology is not adopted except as part of a larger "technology cluster", including organizational changes, subject to the general constraints of innovation diffusion theory (Innes, Green and Thomson, 2005). The adoption of new information and communication technologies (ICTs) can have momentous impacts on individuals and organizations (Thomson and Colfer, 2005). Consideration of other theories, such as Knowledge Management Theory, Escalation of Commitment Theory, Agency Theory and Grounded Theory, can also assist in achieving system success (Thomson *et al.*, 2007a).

2.1.3 Computer programs for data and information management

Thomson *et al.* (2007a) define three broad classes of systems useful in problem solving: descriptive, predictive and prescriptive. Within each class are subclasses that represent different approaches to providing each class's tools. Relational databases and geographic information systems (GIS) are the primary software products used in information management (Tokola *et al.*, 1997). However, data may be moved between these programs and other systems, such as spreadsheets,

statistical programs and models, during the analysis and reporting phases of an NFA, and word processors may also play a significant role, especially in relation to interview data, as described above. Word processors can also include dynamic links to spreadsheets and databases to automate reporting. Data-mining tools, facilitated by standardization, may also be used (Miles, 2001). Customized user interfaces may be developed to enhance the operations of these programs. Predefined report layouts (see section 2.4, p. 101) are used with such programs (Tokola *et al.*, 1997).

2.1.4 Standards, metadata and data quality

Many of the difficulties described in section 1.3 (p. 95) can be categorized as issues of poor data quality. For "traditional" types of data, such as area, growing stock, increment and fellings, quality is often satisfactory, while for some of the more recently introduced parameters, such as forest condition, protection status and provision of non-wood goods and services, problems with quality are more likely (ECE, 2000).

Quality and currency can be achieved through data registration (see section 3.1.2, p. 102), with the responsibility for keeping data up-to-date delegated to individual entities such as local offices (Nolte, 2006), although lack of local expertise may be an obstacle to this process (EC/FAO Partnership Programme, 2000). Data quality has a human element, such as errors at entry, which can be minimized through use of technologies such as data loggers (see section 2.1.2, p. 96), errors in reporting as a result of overwork (Michalek, 2002: 30), biases or misinterpretation of questions (ECE, 2000: 227). However, this section focuses on computational issues in which quality assurance can be achieved through methods such as use of appropriate standards, metadata, validation and verification, backups and archiving. These methods not only improve data quality, but also facilitate comparability among assessments. Users, administrators and developers have different issues (FAQs) with regard to standards, metadata and data quality (Anon, 2009b).

Standards: Standards can be employed in three main arenas: content, classification and technology. Standards referring to structure, transmission and meaning of information are known as content standards, and define ways to store and share information unambiguously (Richards and Reynolds, 1999). Standards not only apply to data input; appraisal of data sources helps to identify information quality for inclusion in assessments. Standardized criteria for objective evaluations of information source reliability are required, but are not easily developed or carried out (FAO, 1998). Systems are evaluated not only in relation to their standards, but also in relation to vocabulary and technology used, protocols implemented and level of interoperability (Pesce, Maru and Keizer, 2010). Quality assurance of data supply can be conducted within the framework of a standard such as ISO 9000.

The systems of nomenclature applied in NFAs are characterized by tradition and national information needs, and are not standardized internationally. Even identically named attributes may mask different concepts and definitions (ECE, 2000). Differences in definitions and measurement rules can be made compatible in two different ways: standardization and harmonization. Harmonization falls is discussed in section 2.2.2 (p. 99), but the distinction will be clarified here: "Harmonization relates to attributes that are already defined in different ways at the national level. The harmonization process seeks for a common agreement on how data can be converted to meet a harmonized definition, which is often the union of similarities of existing definitions, and does not necessarily eliminate all inconsistencies. Standardization introduces a new, common definition or standard that is applied in all national programmes. The standard eliminates all inconsistencies but can be quite different

from individual, national approaches. Standardization can be seen as the process necessary for definitions of attributes that are not yet assessed but have to be introduced in national programmes. Harmonization is related to using already existing national systems of definitions but endeavouring to bring the definitions into alignment through incorporating 'adjustments' for the known differences" (ECE, 2000: 27).

Standards can include dictionaries, definitions (Lund, 1998), ontologies and semantic webs, nomenclature, thesauri and gazetteers. Agreement on common classifications and definitions involves compromises: for example, the threshold of 40 percent crown cover to distinguish closed from open forest is frequently debated. During Kotka III, one non-governmental organization recommended a threshold of 70 percent crown cover for defining closed forests. There is no single classification system that will serve and satisfy all needs. What is essential is that the classification criteria are clear and can be applied objectively.

Metadata and meta-information: A metadata standard is a common set of terms and definitions that describe data, outlining the characteristic properties to be recorded as well as the values the properties should have. It provides a way for data users to know what data are available, whether the data meet their specific needs, where to find the data and how to access them (GeoConnections Secretariat, 2001a). Metadata includes the who, what, where, when, why and how about every facet of the data or service being documented, such as details regarding the data's ownership, quality and time of collection, as well as updates or transformation and attribute information. It can include details regarding accuracy, reliability, precision and significance of the data. Metadata standards are especially well developed for geospatial data. Meta-information, on the other hand, are data about any form of information resource, including organizations, people, documents and services, as well as datasets (Richards and Reynolds, 1999). In recent years, FAO has become increasingly involved in social computing (IIED, 2009), which requires its own metadata (Greenberg and Klas, 2008).

The Global Forest Information System (GFIS) developed by the International Union of Forest Research Organizations (IUFRO) is a distributed network of meta-databases that catalogue the information resources of contributing GFIS partners. GFIS functions by providing a standardized core of metadata (catalogue) fields, a standardized set of keywords on which to search, and a standardized interface between websites and databases, enabling them to function in an interoperable environment (Päivinen *et al.*, 2000, 2001). Distributed networks and interoperability are discussed in section 3.1.1, p. 102. The Dublin Core, used by the European Forest Information System, consists of 15 basic elements: title, creator, subject and keywords, description, publisher, contributor, date, type, format, identifier, source, language, relation, coverage and rights (Päivinen *et al.*, 2000). Dublin Core metadata concerns semantics: what one is trying to say about resources. Notes and comments without which forest resource information could not be properly interpreted may be regarded as an informal form of metadata.

Verification and validation: A key principle of the FAO FRA 2000 process was that information should be verified. This means that all data items should have a source reference, and that data processing should be transparent, with countries then validating and approving information concerning their country before publication (FAO, 1999b). This requires much manual work to maintain and update data, and the process of gathering, verifying and cross-checking information competes for the time of agencies also involved in other key processes (Bureau of Rural Sciences, 1998). FAO is now pursuing integration of data quality indicators into the FAO statistical system (FAO, 2005).

Backups and archiving: The organization of existing information is a task that may be tedious, but which can often save much time and money (Janz and Persson, 2002). This process is facilitated by good archiving and retrieval systems, and may be hindered by a lack of safe backup procedures.

2.2 Information

While the previous section dealt with basic issues of data storage and quality control, this section deals with the transformation of data into information. Such transformations are often the result of a demand for specific information. Meeting these demands has major implications for information management.

2.2.1 Information demand and supply

The demand for forest information has changed since forest policy underwent a shift in perspective from timber production to social, economic and environmental issues (Anon, 2002b). Many of the new information needs were recognized in Agenda 21 and have been re-evaluated in the light of advances in internet technology. In recent years, information on topics such as biofuel and ecosystem services has been in demand (FAO, 2010c). In an overview of the supply and use of information for forest policy, Janz and Persson (2002) indicate that "[t]here are serious shortcomings in the supply and use of information needed for policy making … The main weakness is failure to connect supply to demand." However, even when information exists, authorities may desire that it be kept secret. The success of a Forest Information System will depend on the degree to which the information needs of potential users will be satisfied. There is a need to ensure that the information requested at the international level can realistically be supplied by countries (Holmgren and Persson, 2002).

2.2.2 Information aggregation and integration

While the focus of this chapter is on computer-related aspects of information management, the organization of printed and other information may be an essential precursor to computer analyses, as in the FAO FRA "documentation room" (FAO, 2000a). The task of coordinating, processing, harmonizing and managing forest-related databases is necessary to avoid duplication of efforts. There may be "little comparability between surveys performed in different years even by the same agencies and ensuring compatibility of data across varying formats, map projections, boundaries, and scales even within a country is becoming a Herculean task (FAO, 2001a)."

Information transformations: Information to be provided by a forest information system varies according to the purpose and scale for which it is used; information needed on the strategic and integrative level has to be aggregated in both thematic and spatial terms. Adjustment factors may need to be determined, and may be based on ancillary variables such as human population change or ecological zone (FAO, 1998, 1999a). These should be described in the metadata (see section 2.1.4, p. 97). As systems of nomenclature applied in national forest resources assessments are characterized by tradition, and even identically named attributes may mask different concepts and definitions, a major concern of the Temperate and Boreal (TB) FRA-2000 was the comparability of data between countries and the reliability of aggregated results (ECE, 2000). Both the 2005 (FAO, 2006) and 2010 FRA (FAO, 2010a) reports indicate that substantial efforts were needed by the national correspondents to document each step in the transformation of national data to the FRA 2005 and 2010 reporting tables.

Development of adjustment factors is part of the harmonization process introduced previously in section 2.1.4 (p. 97). Harmonization is the process of making reports to different instruments comparable,

for example, through the use of common or comparable terms and definitions, standardized units for data and common reference years (Braatz, 2002). In this process, it is critical that aggregation occur at an appropriate scale (Agarwal *et al.*, 2002). Together, the aggregation and harmonization processes facilitate identification of information gaps (FAO, 2001a). Thomson and Schmoldt (2001) discuss ethical issues of information aggregation, transformation and reporting.

Expert opinion: NFAs are often based on a form of synthesis dependent on partial data plus expert opinion (FAO, 2000b). For example, experts may be used to determine adjustment factors (FAO, 1998). While expert opinion can be subject to bias and imprecision, it is generally better than a complete absence of information. The Delphi Technique and Convergence of Evidence are two methods of managing expert opinion, and the information management system should include methods of tracking these opinions. The increasing reliance on surveys of stakeholders such as indigenous peoples should also be viewed as a use of expert opinion. Thomson (2000) describes an information management system relating to a questionnaire used with Canadian First Nations. The system tracks the literature basis for each question, the range of responses, the inferences drawn (and by whom) and indicators derived.

2.3 Information management and change assessment

FRA 2000 required three types of information on forest change: deforestation, forest degradation and forest plantations (FAO, 1999a). In a FRA, the data sources used in the previous assessments are consulted and new sources are identified (FAO, 1998). Once identified, the new sources are compared with the older information to determine which provides the best and most reliable baseline. Comparability between two (or more) information sources is also evaluated, verifying their utility to serve as representative surveys in a continuous time series. It is the standards and metadata associated with each dataset that permit evaluation of reliability, comparability and verifiability. For example, in some assessments the definition of "forest" changed significantly from earlier definitions, now including large areas of woodland not previously defined as forest (Bureau of Rural Sciences, 1998). Definitions are one of several features identified by Hansen, Stehman and Potapov (2010) as limiting the utility of NFA data for use in global forest change assessment.

Change assessment often relies on models (FAO, 2000b). For example, deforestation has been predicted from accessibility and the income-generating potential of tree and forest land (FAO, 1999a), and models have also been used in relation to plantations and wood supply (EC/FAO, Partnership Programme, 2000). Information management plays a key role in the integration of models into assessments. The flow of information should be considered explicitly in the development and use of models (Agarwal *et al.*, 2002). From a user perspective, linear projections and expert opinion, rather than modelling, were preferred for adjusting forest area estimates to a common reference year for countries with inadequate data sources, as this approach was believed to reflect more accurately the uncertainty surrounding inventory data on forest cover and change rates in much of the tropics (Matthews and Grainger, 2002).

2.3.1 Data and information sources

Information management plays a major role in tracking fellings and removals, afforestation and reforestation, and forest degradation. These are often managed at the local forest management unit level, and the data sent to a central location for integration into a regional or national perspective. This process involves intercomputer communication (see section 3, p. 102).

Change resulting from forest degradation

poses particular challenges for information management. Each source of degradation may have its own information requirement, for example, forest fires (FAO, 2000c). In many countries, there are no formal inventories of forest health, although major inventories of tree defoliation exist in both Europe and North America. In many cases, expert opinion (see section 2.2.2, p. 99) represents the best available estimates for particular damaging agents, rather than the results of specific surveys and inventories. Substantial differences exist in the values obtained by observers both within and between different countries (ECE, 2000). The existence of different concepts of damage and different definitions of defoliation hinders change estimation and emphasizes the need for standards.

2.3.2 Monitoring

The TBFRA experience provides a valuable perspective on monitoring change relating to the issues raised in section 2.2.2: "change (in any parameter) is not usually measured directly: rather measurements of the same parameter are taken at different time intervals, but with the same methods and definitions, and then compared. It is essential to separate 'changes' due to changes in methods or in definitions from those really arising from changes in the parameter measured. Definitions and methods used in the international FRA programmes have changed, sometimes significantly over the past decade (not to mention the many more changes at the national level), so it is not possible to draw any reliable conclusions from a comparison of TBFRA-2000 data with those in earlier international assessments." For REDD purposes, monitoring limitations include issues of consistence, transparency, comparability, completeness and accuracy (Herold, 2009).

2.4 Reporting and communication

Information management is a key component of meeting national and international reporting requirements. With the overflow of information it is becoming increasingly important to present information and knowledge in an interesting, easily available and digestible form (FAO, 2001b). Governments and organizations need to ensure that information and knowledge are neutral, objective and widely disseminated in a timely manner, but must avoid information overload (FAO, 2003). Traditional forms of communication must supplement the digital flow of information. Automated reporting aspects of information management can help to tailor information to specific audiences and sectors. Schiller *et al.* (2001) discuss ways of communicating assessment results to decision-makers and the public, especially where the results concern indicators. The wide use of the World Wide Web for reporting and communication is discussed in section 3 on intercomputer communication (p. 102).

2.4.1 Reporting requirements and information management

International reporting requirements can become a considerable burden on countries, and some information requests are duplicative and redundant (Braatz, 2002). Reporting obligations can overlap, and without coordination confusion is likely (Schoene, 2002). Automated reporting can reduce this burden and minimize confusion. Maintaining consistent definitions can further alleviate the burden, and duplication of effort for variables that are reported to several agencies can be reduced by collaboration with other reporting processes. For example, variables in forest biomass and carbon have been harmonized with the specifications of the Intergovernmental Panel on Climate Change (IPCC), and variables on endangered species have been harmonized with IUCN 2000 (FAO, 2010a).

2.4.2 Maps, graphs and statistics

Computer programs for generating maps, graphs and statistics, which can be included in reports, are described in section 2.1.3 (p. 96), and Thomson and Schmoldt

(2001) discuss ethical issues of their use. Appropriate information management can mitigate problems of countries changing name, splitting, merging or changing their administrative units (FAO, 1999b). However, forest information provided by countries needs to be scrutinized carefully because it is often political in character (Holmgren and Persson, 2002). Some countries may want to hide their high deforestation rates, while others may want to exaggerate figures so as to seek increased assistance to forestry.

Reported forest conditions depend highly on the national policy context, and countries may exert pressure to hide information that they consider embarrassing. Information is sometimes released or interpreted to fit a policy purpose, and this usage erodes confidence in forest information. Information management is therefore closely linked to higher institutional issues, particularly if automated report generation is used, especially online.

3. Extending the basic scenario: many institutions and many computers

3.1 The internet and other computer-related issues

Rapid development of the internet, and particularly the World Wide Web, have radically changed information management for forest resource assessments in two major areas: (i) distributed information management and (ii) responses to remote requests (in the form of searches) for information. Familiarity with web browsers and web search engines such as Google is commonplace, and web-based information (and computer-based information in general) is well accepted, although acceptance varies with culture. Such search engines give results based on combinations of words in existing webpages, but when information is contained within databases, a more complex approach is required (Richards and Reynolds, 1999). Searches for geospatial data further complicate the situation.

3.1.1 Distributed systems and interoperability

Data and information sharing is greatly facilitated by a common set of definitions and schema for common coding (FAO, 2001b), such as the use of standards and metadata as described above (section 2.1.4, p. 97), including the Z39.50 Information Retrieval standard. Success is based on concepts of interoperability: "the ability of a system or a product to work with other systems or products without special effort on the part of the customer". Subdivisions include: technical interoperability, semantic interoperability, political/ human interoperability, inter-community interoperability, legal interoperability and international interoperability: "to be interoperable, one should actively be engaged in the ongoing process of ensuring that the systems, procedures and culture of an organization are managed in such a way as to maximize opportunities for exchange and reuse of information, whether internally or externally" (Miller, 2000). The interlinking of systems, people and institutions is the main tenet of interoperability (Thomson, 2005).

The interoperability of web-mapping services is described by the GeoConnections Secretariat (2001a). A Web Map Service (WMS) is an online service designed to display maps and/or images possessing a geographic component, and whose raw spatial data files reside on a server or workstation. Portals such as the Canadian GeoConnections Discovery Portal can provide a single access point to distributed information and resources. The FLAMA system illustrates distributed systems and interoperability considerations in forest fire systems (International Space University, 2005).

3.1.2 Data registration

In many respects, data registration is the converse of search with information being uploaded to an information system rather than downloaded. Data registration is generally a two-step process: first the organization is registered, then the data products and services (GeoConnections Secretariat, 2001a). Unregistered users can generally freely browse information contained in such databases, but may not submit new information. Once the organization is registered, information can be submitted. Downloadable metadata templates or other software tools facilitate submission of information. One reason for registering data at source is to take advantage of the knowledge each supplier has concerning their own data and local conditions, as well as to ensure continued and timely updating (Forsberg, Frisk and Rönnqvisty, 2005).

The IUFRO GFIS system is an example of an open system to which information providers, using GFIS standards for cataloguing information, may contribute content. To assist this process, a GFIS "collection policy" defines subject coverage, target audience, types of resources to be included, submission procedure, quality assessment, metadata standards and maintenance arrangements (Päivinen *et al.*, 2000, 2001). This indicates that data registration is only part of a process that includes computer, human and institutional components. Data ownership and security (FAO, 1999b) must be addressed during this process, and are often key factors in institutional agreements. Legality verification of certification for timber procurement purposes can also include data registration (Simula, 2010).

3.1.3 Institutional and infrastructure issues

The national legal, policy and institutional framework relating to forests constitutes the fundamental basis for sustainable forest management. For FRA 2010, countries were asked for the first time to report on these topics and significant progress was found to have been made in developing forest policies, laws and national forest programmes (FAO, 2010a).

Coordination of data collection and exchange among national institutions, constituent states and donor agencies is a major weakness in most countries, and terms and conditions of funding agencies may be a major constraint. Officials may be reluctant to pass on information (Sithole, 2002), and there is lack of enforcement of penalties against companies that do not send (or delay sending) required data (EC/FAO Partnership Programme, 2000). More than one ministry often supervises forest information collection activities. Good cooperation makes these activities possible, but may be hindered by a lack of formal regulations, particularly concerning reporting for international assessments (Michalek, 2002). Institutional change may be required to achieve interoperability (Miller, 2000), and completely new institutions (analysis units) may be required to properly provide required forestry information (Janz and Persson, 2002).

Supply of information may involve framework agreements and contracts, policies (Global Spatial Data Infrastructure) or Memoranda of Understanding (IUFRO, 2002). Issues of participation may also require institutional or infrastructure changes, with significant impact on the information to be managed as well as on reporting requirements (see section 2.4, p. 101): "The availability of high quality information and knowledge is a key to effective participation and needs to be made available in a transparent manner to the broad range of actors involved in national forest programmes processes. For this, systematic efforts in capacity-building are required" (Joshi, 2009).

4 Putting a full national forest information system in place

4.1 System design and development

Formal project management processes, of which there are many examples, can aid system design and development. A requirements analysis is used to determine purpose and objectives, clients and drivers, and usage. The requirements analysis must be developed in the context of organizational issues, implementation plans, evaluation criteria, hardware software and networking issues, and standards (US Army, 2005).

4.1.1 Requirements analysis

The requirements analysis should result in a clear statement of end-product characteristics and estimated data volumes, and can have subactivities such as system requirements analysis, data requirements analysis and business requirements analysis. The system requirements analysis, in turn, can include topics such as objects, data, relationships, processes, narratives, business rules, access paths, data integrity and information design. Human-computer interactions and interface designs are defined. The requirements analysis must take into account issues such as laws (Michalek, 2002) or policies (Anon, 2002b) relating to access to information. A requirements analysis has been developed for the spatial data handling within the EU Plan4all project (Anon, 2009c).

4.1.2 System development

Based on the requirements analysis, an architecture (GeoConnections Secretariat, 2001b) and operating system will be determined. Decisions on whether to use a proprietary software or open-source software, often referred to as FLOSS (i.e. free/libre and open-source software), will have a significant effect on system development, as will the decision to develop the system from scratch or adapt an existing system. The choice of software products will determine the availability of tools (Richard and Reynolds, 1999) and reuseable components, and may be predetermined by existing enterprise-wide computing requirements (Beck, 2001). Human resource and training requirements may have to be addressed at this stage, including the identification of different categories of training, such as webmasters, librarians and documentalists, and end users (IUFRO, 2002). Pilot projects may need to be established and benchmarks and testing protocols implemented, and intra and inter-institutional agreements must be formalized.

Building a system "is a continuous process rather than a one-time event. After installation, there will be new requirements and additional functions to be added. Hardware and software will need to be upgraded. Maintenance of the system must be planned and taken into account. System sophistication cannot exceed the available long-term resources and in particular local capacities. System development relying in external know how should be used only with a credible exit strategy building local capacities" (Steudler, Törhönen and Pieper, 2010).

4.1.3 Funding and financial mechanisms

The costs and timeliness of information is a key factor (Janz and Persson, 2002) and costs of providing forest information can become a major concern (Bureau of Rural Sciences, 1998). How an NFA is funded, and who pays for what, depends to some extent on whether information is regarded as a public or private good (FAO, 2000d). A business case for an information management system (Centre for International Economics, 2000) resembles a requirements analysis, establishing the magnitude, nature and likely influences on demand for the product to be developed, identifying the risks and uncertainties, and including costs and benefits with the goal of obtaining funding. The funding mechanism

may incur substantial information management and reporting commitments, and become potentially a limiting constraint, as in the case of Bangladesh (EC/FAO Partnership Programme, 2000). Some costs may be offset by income from data provision; however, data pricing may be implemented at the national policy level.

When national forestry information systems are under-resourced and filled with gaps, or use imputed values that are prone to gross errors, they are unable to deliver reliable data in a timely manner. Users then dismiss their services, which reduces funding and results in continuous poor performance, creating a vicious circle. In recent years, donor programmes have concentrated on collecting information rather than building capacity, although this is slowly changing with an increase in investment in capacity. Technical options may be understood in some countries, but organizational and financial aspects are lacking (World Bank, 2008).

5. Knowledge

5.1 Knowledge in the NFA process

As indicated above, while the output of an NFA is information, knowledge plays a key role in the process of collecting data and transforming it into information. Both the 2005 (FAO, 2006) and 2010 FRA (FAO, 2010a) indicated that the data transformation efforts involved extensive knowledge sharing through discussions at regional workshops, and between countries and regional focal points at FAO headquarters. This is particularly the case where stakeholder participation is involved (see section 1.2, p. 95). The NFA process is therefore a complex and many-faceted arrangement of people, institutions, organizations, technologies and processes in which knowledge is created, interpreted, distributed, absorbed, translated and utilized. In other words, it fits the definition of a knowledge ecosystem (Thomson, 2006, 2007).

5.2 Knowledge ecosystems

In a knowledge ecosystem, knowledge held by different individuals, and within different organizations/institutions, is shared in groups subject to effects that are drawn by analogy with biological systems, including competition, pyramidal concentration, pollution, drift, meta-population features, sustainability and resilience. As each concept is applied when evaluating a particular organization's/institution's ecosystem, sets of questions arise that provide helpful guidance for institutional change (Thomson, 2006; 2007). A knowledge ecosystem can evolve with time, as illustrated in a case study on development of web-based technologies in support of sustainable forestry (Thomson, Callan and Dennis, 2007b).

6. Discussion

Information management deals with the flow of information all the way from data entry in field-recording devices to the generation of reports to balance the needs of many information users (Päivinen *et al.*, 1998), and to meet national and international commitments. Information may be initially gathered for other purposes such as certification (Simula *et al.*, 2002) and subsequently used in NFAs. Technological aspects of the process are well defined, as are administrative and project management processes to facilitate system development, and it is leadership, policies or institutional and organizational issues, often relating to funding and support, that become major constraints. Where there is adequate institutional and organizational support, the "digital divide" (FAO, 2001b) can also be a restriction. However, initiatives such as the UN Task Force on Information and Communication Technologies (UN, 2003) may lead to rapid improvements in this area.

Each successive FAO FRA process has seen a change in scope and content in response to changing information needs. The first assessment focused on timber shortages, then from the 1970s through to FRA 1990 deforestation was of particular interest. FRA

2000 covered a wider range of forest benefits and functions and FRA 2005 was based on the concept of sustainable forest management. FRA 2010 continued this broader, more participatory approach and included the legal, policy and institutional framework guiding forests and their management and use (FAO, 2010a). National FRA processes have seen increases in the extent and complexity of inter-institutional relationships, in the need for improved interministerial coordination, and in the level of knowledge required to prepare the data and information for reporting. Both information management and knowledge management must be coordinated to meet the many needs of the present and to prepare to meet the demands of the future.

Aggregation	Funding	Programmes
Backups	Harmonization	Registration
Communication	Infrastructure	Requirements
Currency	Integration	Sources
Data models	Interoperability	Standards
Data quality	Maps, graphs	Transformations
Demand/supply	Metadata	Validation
Devices	Monitoring	Verification
Experts	Ontologies	Vocabulary

Self-study exercises

1. The knowledge ecosystem concept includes "competition". What international treaties/agreements does your country subscribe to that would require your NFA to produce reports?
2. Which agencies/units were involved at each stage of the process to transform forest plot data into the entry for your country in FAO's 2010 global assessment, and what programmes and systems were used?
3. Give three examples of system failures that have been reported in your country (or a country of your choice) and list the stated causes.
4. A donor agency is funding development of an information system for your NFA and you have to perform a requirements analysis for the system. From the following list of system design considerations, rank the top five issues for your system, giving reasons.
5. Which of the following is most limiting to development of your countries' NFA information system: technical interoperability, semantic inter operability, political/human interoperability, intercommunity interoperability, legal interoperability or international interoperability

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Modelling for estimation and monitoring

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THIS CHAPTER DISCUSSES THE FOLLOWING POINTS:

- The use of models and data aggregation in NFIs and NFAs.
- Estimation and modelling of biomass and carbon content in forested ecosystems.
- Aspects of model predictions, model quality, model errors and model bias.
- Issues in estimation and modelling of temporal change in NFI attributes.

Abstract

Many attributes of interest in forest inventories must be estimated using lookup tables or equations, collectively referred to as models. Stem volume, for instance, is rarely measured directly in the field, but is instead estimated from dimensional measurements such as diameter or height. Individual observations are usually aggregated for reporting purposes and may be grouped during field data collection, for example, when trees are tallied by diameter or height class. Aggregation simplifies presentation of data, but reduces the information content.

Equation-based models are used frequently to estimate variables such as volume, biomass or carbon content. However, it is sometimes difficult to judge whether a given equation is applicable to a particular situation. It is therefore important to assess the quality of all equations used in an inventory. The selection of a particular equation should be guided by this assessment, as well as the modelling objective and context.

Some inventories focus on assessing the state of the resource, while others concentrate on changes in the resource over time. Different field procedures and sampling designs are preferred for different objectives. Sampling with permanent plots provides estimates of both state and change. Designs with a smaller (and more expensive) set of permanent plots and a larger set of (less expensive) temporary plots can also provide good estimates of both state and change, but the statistical analysis of such designs is quite complex and care must be taken to ensure appropriate assessment of accuracy and precision.

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1. Introduction

Many attributes of interest in forest inventory and monitoring applications are not measured directly, as to do so would be impractical or costly. The best-known example is stem volume where diameters and heights are measured on individual trees and a table or equation (collectively referred to as a model) is used to estimate the associated volume (Köhl, Magnussen and Marchetti, 2006, section 2.37). The volume of coarse woody debris (CWD) is another example (ibid., section 6.4.6; Woldendorp *et al.*, 2004). In practice, only a small number of short segments of CWD are measured for volume, while the total amount in an area of interest is estimated through scaling of the measured pieces, the scaling itself depending on the sample design (Woldendorp *et al.*, 2004). Advances in remote sensing favour the use of easy-to-measure and readily available variables (say X) correlated with attributes of interest (say Y). An estimate of Y for the area or population of interest is then obtained from a small sample of Y and knowledge of the relationship between X and Y (Köhl, Magnussen and Marchetti, 2006: 80)

The following sections present the types of models available for indirect estimation of quantities such as wood volume, biomass and carbon content, along with examples. They also discuss important issues to consider in the choice of model for a specific application, in addition to modelling objectives and contexts.

2. Aggregation

Aggregation is the combination of data or observations into groups. Its purpose is to simplify measurements and data processing (Stage, Crookston and Monserud, 1993) or to summarize data and observations into groups and categories of interest.

The data collected on attributes in a forest inventory are defined and prescribed according to the information needs of stakeholders (Dachang and Cossalter, 2006: 5). In a field inventory, it is important to measure and record all items in a sample plot that meet the definitions/specification of the desired attribute (for more information see chapter on *Observations and measurements*, p. 41). Data definitions/criteria can be based on demographic characteristics. In the case of trees, for example, this could be a minimum size limit, often expressed as a minimum diameter (e.g. 10 cm). Criteria may also limit measurements to certain species or tree characteristics of interest.

It is important to remember that limiting inventory data and observations to items (e.g. trees, shrubs, snags, etc.) that meet established definitions/criteria equally limits the inference and estimates that can be derived from these data to the parts/units of the forest population that satisfy the definitions/criteria. For example, if stem-wood volume estimates for live trees are estimated only for trees with a diameter at breast height greater than 10 cm, then it will not be possible to estimate total volume or biomass for the forest of interest. To paraphrase, the results apply only to population elements with a known positive probability of being included in the inventory sample (Thompson, 1992: 21) (see section on sampling design and estimation).

Sample unit summaries do not usually include values for all items measured. For example, trees are often aggregated into groups based on species, demographics such as diameter, height or social status (section 2.2, p. 113), hierarchy such as functional group (section 2.3, p. 114) or the total stand. Aggregation may be one-dimensional (e.g. total volume by species) or multidimensional (e.g. volume by diameter class by species) as appropriate. Aggregation of inventory items can also be based on land-use pattern (e.g. shifting cultivation) or future planned use of a resource item (e.g. fuelwood).

The consequences of any aggregation of observed/measured items on analysis and inference should always be considered carefully (Clark and Avery, 1976). Once data are aggregated, it is usually difficult – if not impossible – to recover underlying details at a later stage, should it become desirable

(Ritchie and Hann, 1997). To conserve a desired accuracy and precision of estimates, it is often better to postpone aggregation to the analytical phase that follows completion of field data collection. However, for practical and cost-saving reasons, aggregation often occurs during field observation. Instead of measuring, for example, the diameter of each tree in a field plot to the nearest 0.1 cm, counts of trees by 5 cm or even 10 cm diameter class are often practised due to expediency. In this case, the class midpoints are usually used in the analytical phase. It should be noted that an aggregation always has the potential to introduce additional error and possible bias in the resulting estimate (Ducey, 1999). Of course, aggregation greatly simplifies field procedures and may well result in greater overall precision if the savings due to efficiency are used instead to collect more field data; however, the trade-off is far from simple, and it is important to reiterate caution against uncritical aggregation.

2.1 Aggregation by species

Estimates of totals and per unit area values for a stand, forest or region, are frequently aggregated over species meeting a certain definition/criterion with respect to size or use. As stated above, it is important that all species that enter the inventory sample – and otherwise meet the definition/criterion – be duly observed and recorded. Otherwise the estimates will become biased. In cases when the field crew is unable to identify a species, it should be given a name with indications for later identification (e.g. shape or size of foliage, fruit-bodies, branching, bark, etc.). Aggregation by species during field data collection may be acceptable during surveys of biodiversity and in count-oriented surveys of disease and insect damage, but otherwise is not recommended.

It is common in temperate forests to develop estimates of stand characteristics by species. In tropical forests, this can be difficult and may prove even more difficult to interpret, due to complex stand structures or the large number of species (Higgins and Ruokolainen, 2004). In some instances, species are combined by ecological functional group (e.g. canopy dominants). This often results in a manageable number of species groups that are relatively easy to interpret in terms of forest structure (Gadow, 1999). Commercial utility and silvics are also considered for species grouping.

In national or continental scale summaries, species groups may be developed for reporting purposes due to the large numbers of potential species (Burns and Honkala, 1990). A species group labelled "pine", for example, may include all *Pinus* species occurring within a geographic area of interest.

2.2 Aggregation by size

Trees are often aggregated by demographics with the result that trees of similar sizes or social status are combined into groups for data summaries or field data collection. Aggregation by size for reporting and analysis purposes is generally straightforward, except when the inclusion probabilities (viz. expansion factors) associated with the inventory data are linked to the size of trees (Köhl, Magnussen and Marchetti, 2006: 155).

Aggregation of trees by diameter (e.g. 5-cm diameter class) is probably the most common method of aggregation in the field. The number of trees in each diameter class is tallied and diameter class midpoints are used in the subsequent analyses to estimate variables such as volume or biomass. The minimum diameter of trees to be measured is usually specified in the field measurement protocols. Thresholds for inclusion/measurement are defined according to the purpose of the survey. Usually, the minimal commercial diameter is used, or one to two diameter classes below that threshold. Stratification of sampling efforts by size is an inevitable practical constraint when sampling odd-shaped, highly variable and scattered objects. An example is sampling for coarse woody debris (Roth *et al.*, 2003; Williams, Ducey and Gove, 2005).

If trees are selected with a probability

proportional to their size, the use of diameter classes can be problematic (Ducey, 2000). Since forest inventory data are often used repeatedly for many diverse purposes, it is preferable to keep data in the form they were captured. For example, a user wanting to model the diameter distribution (Cao, 2004; Gove and Patil, 1998) would be better served by non-aggregated data.

Trees may also be aggregated by height class, which may have a bearing on the resulting wood products that may be derived (Köhl, Magnussen and Marchetti, 2006: 36). Height class may also be used to aggregate trees for analysis of grazing forage availability or wildlife habitat structure (Spetich and Parker, 1998). Height aggregation is probably more common in ecological or grazing surveys than in surveys that focus on assessment of commercial fibre utilization opportunities.

Finally, trees may be grouped by their position in the forest canopy, such as canopy dominants (Gargaglione, Peri and Rubio, 2010; Nigh and Love, 2004). This type of classification is more useful in ecological surveys than in surveys attempting to inventory commercial material. Structural classification may have a great deal of importance in evaluating forage potential or other non-fibre commercial potential.

2.3 Aggregation by hierarchy

Trees may be aggregated in various hierarchical systems for analysis and reporting (Mairota, Florenzano and Piussi, 2002). Trees may be aggregated in a biological hierarchy (individual trees → species → ecological functional group→ stand) or a utilization hierarchy (individual trees → diameter class→ product class → species → stand). Reporting may include summaries for any or all levels of the hierarchy.

Aggregation also occurs at the spatial scale (e.g. Wolf, 2005). The spatial unit can be a stand or a smaller unit (e.g. a pixel in a remotely sensed imaged). Aggregation is then undertaken across all units that meet a certain requirement relating to their forest attributes or data values. Spatial aggregation may be used for reporting and analysis or to improve sampling efficiency by stratification (Köhl, Magnussen and Marchetti, 2006: 105). During analysis of spatially aggregated data, it is imperative to recover all pertinent information concerning the genesis of the data (observed, sample-based, model-based, predicted, imputed, interpolated, etc.), as well as any available estimates of accuracy and bias. Spatial covariance among aggregated forest resource data types can greatly complicate the statistical analysis of spatially aggregated data (Mairota, Florenzano and Piussi, 2002; Rossi *et al.*, 2009; Schwab and Maness, 2010; Waser and Schwarz, 2006).

In spatial aggregations the spatial units may be aggregated by forest type (e.g. moist tropical) or geographic region for analyses at regional or national levels. Geographic region may be based on political delineations (e.g. state or provincial boundaries) or ecological zones, for example, Holdridge life zones (Ni, Ouyang and Wang, 2005). Aggregation at the stand level may occur after estimation (prediction) of the variables of interest for each sampling unit in a stand. The appropriate methodology for the aggregation is determined by the sampling design and survey objectives. Aggregation may be built into the sampling design through the use of stratified sampling (De Vries, 1986: 31).

2.4 Aggregated class estimation

$$Y_{ij}=A^{-1}\sum_{k}^{n_{ij}} X_{ijk}$$

For trees measured on fixed area plots, estimates of per hectare values are obtained by dividing the respective individual tree characteristics by the size of the area sampled:

Y_{ij} = estimated per hectare quantity of the

measured variable for the i^{th} sampling unit and the j^{th} aggregation class with n_{ij} observations of X;

X_{ijk} = value of the measured variable for the k^{th} tree in the i^{th} sampling unit and j^{th} aggregation class;

A = size in hectares of the individual sampling unit.

For trees measured on variable radius sampling units (see *chapter on Observations and measurements,* p. 41) estimates of per hectare values are obtained by dividing the respective individual tree characteristics by the basal area of the measured tree, and multiplying by the basal area expansion factor:

$$Y_{ij} = BAF \sum_{k=1} \frac{Y_{ijk}}{B_{ijk}}$$

Y_{ij} = estimated per hectare quantity of the measured variable for the i^{th} sampling unit and the j^{th} aggregation class with n_{ij} observations of X;

BAF = basal area factor, equivalent to the basal area per hectare represented by each measured tree;

X_{ijk} = the value of the measured variable for the k^{th} tree in the i^{th} sampling unit and j^{th} aggregation class;

B_{ijk} = basal area in m^2 of the k^{th} measured tree in the i^{th} sampling unit and j^{th} aggregation class.

$$\hat{Y} = \sum_{i \in s} Y_i \times \pi_i^{-1}, \hat{\bar{Y}} = \hat{Y} \times N^{-1}$$

An estimate of a total ($\hat{Y}$) or a mean ($\hat{\bar{Y}}$) for a population parameter – obtained by a probability sampling design – follows the basic principles behind the Horwitz-Thomson estimator (Overton and Stehman, 1995):

where summation is over the units (i) in the sample (s) and p_i is the sample-inclusion probability of the i^{th} sampled unit. For a population with N units, the estimation is sometimes done with a mixture of n sample-based unit-level observations, and N-n estimates derived from models or otherwise imputed (McRoberts, 2006; McRoberts, Nelson and Wendt, 2002). In this case, the estimator for the total is simply the sum of all N unit-level values (observations and estimates). The associated estimator of accuracy may follow directly from statistical theory (Overton and Stehman, 1995). In more complicated cases application of the delta technique is required (Davison, 2003: 33–35).

Estimation of population parameters from units of observation is performed on a routine basis in forest inventories. There are two basic sampling units commonly used in forest inventory applications: (i) fixed area plots and (ii) variable radius plots (e.g. Corona *et al.*, 2010). Transect sampling are special cases of fixed area plots and can be treated similarly in many applications (Hedley and Buckland, 2004). In most cases, estimates of the variables of interest are obtained for each sample unit, and then combined to obtain estimates for the larger area (aggregate) of interest. The method of combining estimates from individual sampling units, and the methods of estimating associated precision of the estimates, depends on the sampling design.

2.5 Implications of aggregation in estimation and modelling

Aggregation during the field data collection phase simplifies field data collection and may improve the relative accuracy. Some of the statistical issues in connection with data aggregation have already been outlined. A summary is provided next.

The potential downside of data aggregation during the data collection phase is the possible introduction of bias and an almost certain reduction in both accuracy and precision of resulting estimates due to the introduction of error (Clark and Avery, 1976). Combining all trees within a species class, for example, results in loss of information on individual tree sizes. Since forest inventory data are typically used for multiple purposes and in multiple combinations, it is in general advisable to limit any aggregation to the

reporting/analysis phase of an inventory.

Decisions about aggregation during field data collection also affect the future utility of the collected data. New and emerging issues important to forestry may require details that were lost due to economic pressures of expediency. It is not possible, for example, to explore numerous aspects of biodiversity if species have been aggregated during field data collection. The increased use of remote sensing techniques in forest inventories (Tomppo *et al.*, 2008) can be viewed as an aggregation process (*in extremis*).

Disaggregation of aggregated data is only possible if one is willing to make assumptions about the frequency distribution of possible data values that have been aggregated into a single value (Papalia, 2010). Only rarely can such assumptions be justified.

3. Volume estimation

Volume is the most widely used measure of wood quantity. It is usually estimated as part of the assessment of economic value or commercial utilization potential. The wood volume may refer to a specific portion or part of a tree or the whole tree. The total wood volume of a tree includes the volumes of stem(s), branches, stump and roots. For standing trees, above ground volume production is generally based on stem wood volume for conifers, but may include branch volume for broad-leaved tree species.

Depending on the measurement objective and local traditions, measurements or predictions of wood cubic volume may refer to total stem volume, total tree volume (stem and branches) or the volume of portions of a tree intended for a specific use (Köhl, Magnussen and Marchetti, 2006: 47). Volume estimates may include or exclude bark and, for above ground estimates, include or exclude the stump. Volume is always a cubic measure and is usually expressed in cubic metres. Merchantable volume, however, is sometimes expressed in other units relating to commercial use (Skovsgaard, 2004).

In the field, the volume of standing trees is typically estimated from such measurements as diameter, or diameter plus some height of interest (e.g. merchantable height, total height or height to a usage specified diameter limit). Subsequent application of suitable volume equations, taper equations or a log-rule will then produce the desired volume estimate (Lynch, 1988, 1995; Tesfaye, 2005; Tomé *et al.*, 2007; Yamamoto, 1994a; 1994b).

Volume may be measured directly on felled trees or logs, but is often estimated from dimensions such as minimum diameter or piece length (Husch, Miller and Beers, 1972). Direct measurement of volume is usually performed by sectioning a tree into smaller pieces assumed to be cylinders (Köhl, Magnussen and Marchetti, 2006: 50). Volume may be estimated for stacks of logs or processed products by measuring their dimensions. Local knowledge is needed to make the appropriate transformation to an estimate of the solid wood volume.

Advances in remote sensing technology, especially Lidar (see chapter on *Remote sensing*, p. 77), now allow field-based estimates of volume for a spatial unit (plot) to be combined with a suite of remotely sensed ancillary variables, in order to obtain either model-based predictions of per-unit area volume or per-tree estimates of volume for trees large and distinct enough to be identified with a high degree of confidence (Maltamo *et al.*, 2004a; Maltamo *et al.*, 2004b; Parker and Evans, 2004; Popescu, Wynne and Nelson, 2003).

3.1 Volume equation forms

Stem volume (V) is usually expressed quantitatively as a function of diameter (D), diameter and height (H) or merchantable length. Occasionally, other variables such as clear bole length are used to estimate volume (Husch, Miller and Beers, 1972). An important consideration is that any variable needed to predict volume should be observed during field data collection. The following two "classic" models are often used (Köhl, Magnussen and

Marchetti, 2006: 50): $V = \alpha + \beta \times D^2 \times H$ alternatively $V = \omega \times D^{\varsigma} \times H^{\psi}$ are coefficients to be determined from specific (small) samples in which tree volumes are carefully determined, or known from previous studies (viz. subject knowledge). When tree height can be expressed as a function of diameter (Begin and Raulier, 1995; Huang and Titus, 1992; Jayaraman and Lappi, 2001; Moore, Zhang and Stuck, 1996; Nanos *et al.*, 2004; Zhou and McTague, 1996) the relationship can be built into a volume prediction based on diameter alone. Tabulated lookup tables of stem volume for a given species, location and stem diameter are called volume-tariffs (Fonweban and Houllier, 1997; Magnussen, 1998; Paine and McCadden, 1988).

The choice of model may depend on the modelling objective and data (Skovsgaard, 2004). The listed equations implicitly assume a single-stemmed tree form and may require modification or replacement for species with a more complex form. At times a volume equation is easier to fit to data after a logarithmic transformation because the transformation brings the model into a linear form. However, a negative bias is introduced when the predicted logarithm of V is converted back to arithmetic units (Baskerville, 1972; Bi *et al.*, 2001; Lee, 1982; Wiant and Harner, 1979). This bias is approximately the order of magnitude of one-half of the residual variance of the equation, at least when it can be justified to assume a normal distribution of model residuals.

In the absence of a trusted local volume equation(s), it is possible to utilize geometric relationships to approximate volume. The volume of a cylinder is simply the area of the base times the height, and the volume of a cone is one-third of the volume of a cylinder with the same area of the base and height. Trees are neither cones nor cylinders, however empirical analyses often indicate that the volume of a single-stemmed tree is between that of a cone and a cylinder, with tree volume often lying between 0.40 and 0.45 times that of an equivalent cylinder. A value of 0.42, for example, gives $V \approx 0{,}42 \times B \times \mathrm{H}$ where B is tree basal area at breast height and H is tree merchantable height. This equation will often overestimate the volume of open-grown trees with more conic form and underestimate the volume of trees with more cylindrical form, and may need to be modified for species with more complex forms. Nevertheless, it does provide a first approximation that can be modified subsequently following local experience.

Volume equations derived from remotely sensed predictors are typically linear (possibly after a logarithmic transformation) with a model form that depends on the sensor type, data resolution and scale (Biggs, 1991; Magnusson, Fransson and Holmgren, 2007; McRoberts *et al.*, 2007; Straub, Weinacker and Koch, 2010; Yu *et al.*, 2008).

Application of any model means that the ensuing estimates are not exact. Estimates derived from models may be biased due to limitations of the model, and in all cases are predictions of the expected value given the value of the predictors (Kangas, 1996). For example, if a stem volume is predicted from D and H using a local volume equation, then the estimated value of V should be interpreted as the average value of all trees in the population with the exact same D and H values. The actual tree in question may have a volume that is either greater or less than the expected value (Gregoire and Williams, 1992). If a model produces estimates that have an unacceptably high level of bias, it may become necessary to either develop an improved model or calibrate an existing model (Erdle and MacLean, 1999; Kangas and Maltamo, 2000; Lappi, 1991).

4. Biomass estimation

Biomass is defined as the total mass of living plant organic matter expressed as oven-dry tonnes or oven-dry tonnes per unit area. Estimates of biomass may be restricted to the above ground portion of the vegetation, trees or tree components (e.g. foliage, wood, etc.) (Gschwantner *et al.*, 2009).

Biomass of a forest stand (compartment) is often proportional to the volume and basal area of the stand. Conversely, the biomass of a single tree is typically proportional to its diameter and height (Teobaldelli *et al.*, 2009). Allocation of biomass to various functional components is related to species, growing conditions and the water, nutrient and energy requirements of individual plants and stands (Gargaglione, Peri and Rubio, 2010; Zhang and Borders, 2004). The carbon content of vegetation is directly related to biomass, as discussed in the following section.

Direct estimation of forest biomass is a labour-intensive and costly proposition. Stratified sampling for a field-based estimation of biomass per unit area is the only realistic approach (Loaiza Usuga *et al.*, 2010). Strata are typically defined based on clearly identifiable components of the living vegetation (e.g. fungi, mosses, herbs, grasses, shrubs, seedlings, saplings, trees and epiphytes). The biomass in each sampling unit is determined by weighing after drying following standard protocols (Gabriëls and Berg, 1993). Sample items (e.g. trees) too large for practical and cost-effective handling are sectioned into smaller piece-sizes, and a sample of the smaller pieces is then taken for biomass estimation. It is vital that the dissection and sample plan ensure an unbiased estimator of the biomass of large items (Ahmed, Bonham and Laycock, 1983; Cancino and Saborowski, 2005; Good *et al.*, 2001; Gregoire, Valentine and Furnival, 1995).

4.1 Biomass components

Biomass may be estimated in total for stands or portions of stands as noted, but information on biomass distribution by plant component is often needed. Biomass components may be divided as necessary for a given application, but often include categories such as stem wood, branch wood, foliage, bark, roots, and so on, with more or fewer subdivisions as needed. A common constraint is that the sum of the component biomass estimates must equal the total biomass for the stands or portions of stands of interest.

In many applications, only above ground biomass estimates are used. There are obviously below-ground components to biomass (e.g. coarse roots, fine roots, etc.), but studies quantifying these values are available for only a small number of species and ecosystems, and are difficult to conduct and typically produce low precision data (Lukac and Godbold, 2010; Macinnis-Ng *et al.*, 2010; Niiyama *et al.*, 2010; Pramod and Mohapatra, 2010; Zhang *et al.*, 2010).

At the stand level, biomass may be estimated for the overstory, shrubs, herbs, lichens, moss and so on. In forested situations, the overstory biomass usually dominates. There are cases where tree cover is low and overstory or tree biomass is smaller compared with that of other ecosystem components. The decision as to which biomass components to consider depends on the choice of ecosystems to be surveyed and the intended use of the information.

Cannell (1982) presents a compendium of worldwide biomass data from a cross-section of ecosystems. The compendium includes ratios for various biomass components for many forest types. As of 2010 this compendium remains the single most authoritative compilation of benchmark biomass figures. A smaller set of biomass estimates can be found in a recent re-evaluation of forest biomass and carbon storage (Keith, Mackey and Lindenmayer, 2009).

4.2 Biomass equations

Biomass equations are used to predict biomass from readily available ancillary variables (X). The equations may predict the biomass of a single tree or the tree biomass on a unit of forest land. Tree-level equations express biomass as a function of tree dimensions (diameter and height). Equations for unit-area predictions of biomass vary according to the ancillary variable(s) (X). Equations driven by field-related X-variables generally apply stand-level attributes such as basal area, mean tree size (height/diameter) or similar aggregates of tree-level attributes. Equations

driven by X-variables obtained via remotely sensed data (Gallaun *et al.*, 2010; Wijaya *et al.*, 2010; Zhao, Popescu and Nelson, 2009) vary according to the sensor type and resolution behind X. In many cases, the biomass used as the dependent variable *(Y)* in these equations is rarely a direct estimate of biomass, but rather an estimate obtained by another set of models that "expands" available inventory estimates of tree and stand attributes to the desired biomass component(s) (Albaugh *et al.*, 2009; Gallaun *et al.*, 2010; Jalkanen *et al.*, 2005; Lehtonen *et al.*, 2004; Levy, Hale and Nicoll, 2004; Schroeder *et al.*, 1997; Somogyi *et al.*, 2008; Teobaldelli *et al.*, 2009; Wijaya *et al.*, 2010; Zhao, Popescu and Nelson, 2009).

Equations applied to forest inventory data are usually developed for particular species or species groups, and may be developed with data collected from narrow geographic ranges. Some examples described below show more widely applicable equations developed through a synthesis of published studies. Cannell (1984) presented equations to estimate stand-level woody biomass from total stand basal area and average tree height for a wide range of temperate and tropical stand types; most of the equations are for temperate coniferous forest types. These equations are simple to apply since they use variables commonly obtained during field data collection. Their application is, as a rule, used for stand-level (plot) estimation rather than for tree-level estimation.

At the individual tree level, Jenkins *et al.* (2003) give composite equations applicable for temperate species across North America. Teobaldelli *et al.* (2009) provide a similar set of generalized equations for five species groups in Europe. These equations could be applied, with appropriate qualification, to other temperate forest types.

An example is presented here of a generalized equation used by Jenkins *et al.* (2003), specifically, the Schumacher equation where total above ground biomass is estimated for individual trees based on an allometric relationship with diameter at breast height: $B = e^{(b_0+b_1 ln(D))}$ where B is total above ground biomass (kg) for trees 2.5 cm and larger in diameter at breast height (D). Coefficients are given for both deciduous and coniferous species groups throughout all regions of the United States. Broad species groupings are utilized (e.g. *pine* and *spruce* with a total of five coniferous and four deciduous species groups). Teobaldelli *et al.* provide equations for the expansion factor (BEF) needed to convert an estimate of growing stock (X) to an estimate of biomass (B). A widely used expansion equation has the form $BEF = b_0 + b_1 \times X^{-b_2}$ whereby X is a measure of the growing stock.

Brown (1997) presents equations for individual trees in tropical forests. For broadleaved species, two equations are presented for tropical dry forests, two for tropical moist forests and one for tropical wet forests. In addition, one equation is presented for palms and another for tropical conifer forests. All of these equations express individual tree biomass as a function of diameter and height, although different specific equation forms are used in different applications.

The biomass of various biomass components is commonly estimated from models of the distribution (allocation) of above ground forest tree biomass to specific components (stem, bark, stump, branches, foliage, fruit/seed). Continuing the example from Jenkins *et al.* (2003), the proportion of the total biomass in the i^{th} biomass component of a tree can be estimated from the tree's diameter at breast height, as in $r = e^{b_0+b_1 \times D^{-1}}$.

It should be noted that the "conversion" from one or more readily available inventory attributes of growing stock to biomass, and then to biomass components via a set of generalized equations, is only simple in principle. Many factors and circumstances can cast doubt on an estimate of biomass obtained with generalized equations (Albaugh *et al.*, 2009; Jalkanen *et al.*, 2005; Lehtonen *et al.*, 2004; Retzlaff *et al.*, 2001). It is therefore

incumbent upon the analyst to exercise great diligence with respect to choice of model and intended application of a chosen model. The limitation and error structure of many generalized models and allometric biomass-allocation formulae are often not well documented.

5. Carbon content estimation

Regional and national estimates of ecosystem carbon content, and change in ecosystem carbon content over time, are important components of any assessment of global carbon cycling and its impact on atmospheric greenhouse gases and climate (Birdsey, 2006; Cairns and Lasserre, 2006; Waterworth and Richards, 2008; Watson, 2009). Several international agreements now require improvements in the ability to assess forest carbon stocks and their change (Dutschke and Pistorius, 2008; Kägi and Schmidtke, 2005; Zhang, Zhu and Hou, 2009).

In this context, it has become increasingly important to quantify the carbon content that resides in forests and forested ecosystems, and its contribution to the carbon cycle. Forest inventories make significant contributions to estimates of carbon in forested ecosystems because the carbon content is relatively easy to assess for the components of the vegetation captured by an inventory (Dupouey *et al.*, 2010; Nabuurs, 2010; Rodeghiero *et al.*, 2010; Tupek *et al.*, 2010). In many cases, vegetative carbon is used as a surrogate for total ecosystem carbon, since it is relatively easy to derive from existing information or ongoing inventory efforts. Total ecosystem carbon, which includes inorganic ecosystem components such as soil, is more difficult to assess, especially if the precision of the estimates must be quantified (Baritz *et al.*, 2010; Loaiza Usuga *et al.*, 2010). Expensive estimates of carbon are typically derived from a few intensively studied plots, each considered as representative of a very large area with similar soils, vegetation and climate.

Today, many unit-area estimates of carbon content in forest vegetation are generated from a suite of explanatory variables (regressors) delivered from various satellite or airborne sensors (Maselli *et al.*, 2010; Sánchez-Azofeifa *et al.*, 2009; Tagesson *et al.*, 2009). Invariably these estimates build on a modelled relationship between field-based estimates of biomass (carbon) and one or more sensor-based ancillary variables.

5.1 Carbon content of vegetation

The carbon content of vegetation is surprisingly constant across a wide variety of tissue types and species (Baritz *et al.*, 2010; Mäkelä, Valentine and Helmisaari, 2008; Munishi and Shear, 2004; Nogueira, Fearnside and Nelson, 2008; Rana *et al.*, 2010; Wauters *et al.*, 2008). Schlesinger (1991) noted that the *C*-content of biomass is almost always found to be between 45 percent and 50 percent (by oven-dry mass).

In many applications, the carbon content (C) of vegetation may be estimated by simply taking a fraction of the estimate of oven-dry biomass (B), as in $\hat{C} = 0.475 \times \hat{B}$. The accuracy of an estimate of this nature is typically not great due to errors in , and one should also expect it to be biased.

For dead material, carbon content is a function of the state of decomposition (Boulanger and Sirois, 2006; Garrett *et al.*, 2010; Mukhortova and Trefilova, 2009; Vávrová, Penttilä and Laiho, 2009; Yang *et al.*, 2010). For material that can still be identified, such as fresh litter or standing dead trees, the above equation may be used to estimate the *C*-content if the mass of the material can be estimated (see section 5.2 below 5.2, p. 121). For severely decomposed material, it may be necessary to determine the *C*-content in subsamples taken from the material collected at a site, and then combine this with an estimate of the total (bio) mass of that class of material before the *C*-content for that vegetative component can be estimated. Even

small errors due to sampling, measurement and handling of the material can have a serious impact on the accuracy of an estimate for a vegetation component that is orders of magnitude larger than the taken sample (Woodall, Heath and Smith, 2008).

The total carbon content of vegetation goes beyond trees. It includes all parts and components of the plant community, such as herbs, shrubs and mosses. Field-based estimation of carbon typically begins with an estimation of biomass and then a conversion along the lines detailed above. To accomplish this task it becomes necessary to stratify the community and sample from each stratum. The necessary strata must be defined based on the composition, structure and extent of the community in question (Clark *et al.*, 2008; Friedel, 1977; Kenow *et al.*, 2007). In some cases, it may make sense to obtain *C*-content estimates for lifeforms such as epiphytes, while in other cases this is irrelevant. The approach follows the above for all classes of vegetation: first, the biomass is estimated in each stratum (component) using appropriate sampling methods and then the ratio is applied to estimate the *C*-content.

5.2 Ecosystem carbon content

In addition to the carbon content of vegetation, it may be necessary to estimate total ecosystem carbon content (Jia and Akiyama, 2005; Wang and Sun, 2008; Wise *et al.*, 2009). This includes biotic as well as abiotic carbon pools. Avian (Pautasso and Gaston, 2005) and mammalian (Desbiez, Bodmer and Tomas, 2010; Plumptre and Harris, 1995) biomass and carbon content is often ignored, since it usually constitutes a small fraction of total ecosystem carbon. At times it may be required to estimate arthropod biomass and carbon content in order to obtain a good estimate of total ecosystem *C* (Fisk, Fahey and Groffman, 2010; Tovar-Sanchez, 2009). Colonizing insects may comprise a significant portion of the total biomass of some systems (Vasconcellos, 2010; Yamada *et al.*, 2003), and abiotic materials incorporated into nests and colonies may also be a significant portion of total *C*.

Soil organic matter is a major abiotic carbon pool (Chang *et al.*, 2010; Rovira, Jorba and Romanyà, 2010; Tipping *et al.*, 2010) of particular importance at high latitudes or high altitudes. This may in some cases be greater than the vegetative carbon. Dead plant material at the soil surface and in the upper soil horizons may also have a significant *C*-content that should be considered in any estimate of ecosystem *C*-content (Fisk, Fahey and Groffman, 2010; Gasparini *et al.*, 2010). McKenzie *et al.* (2000) provide a compendium of methods for field data collection for carbon estimation in soil, litter and coarse woody debris. Quantitative data on forest litter may be sparse. However, several countries with an elevated risk of forest fires may have extensive information, drawn from surveys conducted of elements on the forest floor that significantly increase fire hazards during periods of drought (Fernandes, 2009; Kessell *et al.*, 1978).

The carbon content of litter depends on the stage of decomposition, and can usually be determined from field samples designed for this specific purpose. Application of a ratio approach such as that described for vegetation can be used (see section 5.1), but will often underestimate the *C*-content of the litter layer due to the escape of carbonic gases during the process of decomposition (Fioretto *et al.*, 2007; Hosseini and Azizi, 2007; MacDicken, 1997).

Estimates of soil *C* may be obtained from field sampling. This is the most precise and appropriate method to estimate site-specific carbon content. Field data collection should be used whenever precise estimates of soil *C* are needed, but it is important to consider temporal variation throughout a growing season in large studies that may require an extended sampling period. If a soil classification map for the area of concern exists, there may be information on carbon content for different soil types in the area

(Geissen *et al.*, 2009; Zhang *et al.*, 2010b). A given soil type may yet have different mean carbon content depending on the dominant vegetative cover and land use. Soil under an agricultural field may have a very different *C*-content than a similar soil under a mature forest. Estimates of soil *C*-content may or may not be available for all conditions in an area of concern. Batjes (2009) provides access to an extensive database of global soil physical and chemical properties, including information that may be used to approximate soil *C*-content in the absence of site-specific information. These estimates will be less precise than those obtained from field samples, but may be cost-efficient when high precision, site-specific estimates are not required. In many applications, it may be more cost effective, and ultimately result in higher precision in final estimates, to use a greater number of less precise estimates of *C*-content for individual sampling units, than to measure *C*-content of a subset of sampling units with high precision (MacDicken, 1997). The trade-offs are a function of sampling design and cost, and must be evaluated in that context. It should be noted, however, that if expedient less expensive *C*-estimates are biased, the opportunities for an attractive trade-off between a small sample with expensive observations and a larger sample with less expensive observations can be severely curtailed (Köhl, Magnussen and Marchetti, 2006: 79).

6. Judging model quality

A model summarizes a conceptual relationship between one or more dependent variables (*Y*) and one or more predictors (*X*). The model can be stated as a single equation (e.g. Fehrmann *et al.*, 2008), a system of related models (e.g. Gertner, Fang and Skovsgaard, 2002) or a hierarchical (multilevel) model (e.g. Pedersen, 1998). Models are mostly used for predicting new value(s) of an unobserved entity from available predictors. The volume, biomass and carbon equations given above provide examples of the most basic types of models. A model may be formulated through subject knowledge (Curtin, 1970), adopted from other studies or suggested by apparent trends in observed data. The following references provide access to a broad selection of forest models (Amaro, Reed and Soares, 2003; Dykstra and Monserud, 2009: 276; Schwab and Maness, 2010; van Laar and Akça, 2007).

In forest inventory and biological sciences, data exhibit a large amount of natural variation and models are limited to predicting the expected value of the dependent variable given the input data. The quality of any model is judged by its ability to provide unbiased (accurate) estimates of these expectations and the precision of model predictions. Models with deterministic (fixed, invariable) model parameters generate a single prediction (the expected value) given a set of predictor values. Stochastic models contain one or several parameters that are random (Biging and Gill, 1997; Rennolls, 1995). Hence, they can generate both conditional predictions for a random unit (e.g. a tree, a plot or a forest stand) and population averaged predictions (Schabenberger and Gregoire, 1996).

When fitting a model to data, a comparison of values predicted by a model and the actual values of the dependent variable provide an initial assessment of model quality. It is generally desirable for models to be unbiased, meaning departures from model predictions (residuals) to average to zero for any input, and precise, meaning residuals are distributed tightly around the predicted values.

The quality of a model for prediction purposes is assessed by comparing a prediction of a new observation not used in model development to the actual value of the new observation. Common criteria for assessing model quality include a *t*-test of the hypothesis of a zero mean model prediction error, the variance of model errors, the magnitude of the median absolute deviation (Venables and Ripley, 1994), and the sign test for testing equal medians of the observed and predicted values

(Conover, 1980: 122). The Wald-Wolfowitz runs test can be used to test the hypothesis that the elements of a sequence of model errors along a gradient of predictor values are independent (Conover, 1980: 136). Additional assessments are often geared towards testing the assumption of a normal distribution of model residuals (Brown and Hettmansperger, 1996), an analysis of errors in "curve" models (Ducharme and Fontez, 2004; Huang, 1997), and the homogeneity of error variances across a range of inputs (McKeown and Johnson, 1996; O'Brien, 1992; Shoemaker, 2003: 432;). Reynolds (1984) provides a basic approach to model quality assessment. Vanclay and Skovsgaard (1997) provide a brief overview and an operational framework for judging model quality. Some common assessments of model quality exclude a portion of the data from the model-fitting phase or use a leave-one-out cross-validation approach whereby repeated model estimations leave out one observation and then compare the actual and predicted value for the withheld datum (Efron, 2004). The latter approach is preferred, since a large portion of the data can rarely be withheld without affecting the properties of the assessed model. In summary, fewer observations for modelling may result in the chosen model being supoptimal. When sample sizes are small, model-building based on robust techniques is recommended (Choi, Li and Zhu, 2010; Lange *et al.*, 1989; Wang and Leng, 2007).

When applying a general model, such as the volume and biomass equations shown earlier, or a model developed for a given species in a different geographic area, it is important to attempt to assess model quality prior to application. This may require the collection of new field data, although it may be possible to utilize existing data for this purpose. Failure to assess model quality forces the user to make an untested, implicit assumption that the model used is appropriate for the species and geographic area to which it is applied, which may or may not be true. Users of models should always keep in mind that a model may generate unusual predictions. Extrapolations (application of models with one or more of the predictor values falling outside the range of the data used during model fitting) should be avoided whenever possible because bias and precision may quickly become unattractive for otherwise well-founded models (Schreuder and Reich, 1998).

With the advance in models that rely on input from remotely sensed data, it is increasingly important to verify that the predictors are actually the same as the data used during model fitting (i.e. with identical information content, collected at identical spatial scales and with identical measurement error-structures). If this is not the case, the impact of errors-in-variables must also be considered (Carroll, Ruppert and Stefanski, 1995; Fuller, 1987).

Users of existing models are rarely in a position to conduct a full-fledged model check or even a validation. Key information about the statistical properties and data behind a model is often missing or difficult to retrieve.

Instead of relying entirely on model predictions a better strategy may be to take a small probability sample of the variable(s) of interest and then combine them with predictions from a model. This model-assisted type of estimation (Särndal, Swensson and Wretman, 1992) has become popular. In the statistical literature the approach goes under the name of "Small Area Estimation" (Pfeffermann, 2002; Tomppo, 2006). Users concerned with the quality of a model may also adopt a Bayesian paradigm, whereby user-defined prior distributions on model parameters capture model uncertainty and possibly bias, and integrate this uncertainty into their predictions (Gertner, Fang and Skovsgaard, 2002; Green *et al.*, 1999; Green and Strawderman, 1996; Green and Valentine, 1998).

Validation of complex models for large-scale applications (e.g. ecosystem predictions of carbon content) is rarely possible. Validation of individual components of the model may not guarantee that all interactions of the

model components are adequately captured. It is always the user's responsibility to check model assumptions and model predictions.

7. Model error contribution to total error

Methods to ascertain the precision of inventory estimates are dependent on the sampling design used to collect the data. These methods, however, generally assume that the individual observations are measured without error. For model-based estimates such as volume, biomass and carbon, however, there are model errors to consider. Consequently, there are three main sources of error: measurement error, model error and sampling error. Sample-based precision estimates should, therefore, be considered as underestimating the variance, or conversely as implying confidence intervals that are too narrow for derived variables such as volume, biomass or carbon content. Similarly, methods of estimating the sample requirements to achieve a desired level of precision will indicate fewer samples than really needed, unless consideration of model error is taken into account in addition to sampling error.

Inventory models are never perfect. The discrepancy between the actual (unknown) value (Y_A) and the predicted value from a model (Y_P) is called the model error (ε_P). In equation form, this becomes: $Y_A = Y_P + e_P$. This simple (linear) equation also implies that the variance of a series of predicted values is less than or equal to the variance of the actual values. Equality holds only for perfect models with no error variance. For example, if we predict the volume of trees in a plot from a suitable volume equation then the calculated variance of the volume predictions will be less than the actual variance of the volume of the trees in the plot. Consequently, the standard error of a predicted mean volume for a plot will be biased downwards. The variance of prediction errors must be included to obtain an unbiased estimate of the total error.

In many applications it should also be considered that the parameters in models used in an estimation procedure are themselves estimates with associated errors. One may choose to include also this extra source of uncertainty in the estimation of the total errors. For sample surveys with large sample sizes this type of model error would usually constitute a large portion of the total error (variance)

The variance of prediction errors may be substantially larger than the residual variance obtained during model fitting, especially when the mean and covariance of the input variables vary from those of the data used for model fitting. Application of the model outside the recommended application domain raises the spectre of serious additional underreporting of error.

8. Monitoring over time

Monitoring over time allows estimation of change and trends in forest attributes (Köhl, Magnussen and Marchetti, 2006: 143). The changes and trends can be estimated from a set of permanent sample plots (see section 8.1) or temporary plots (see section 8.2) or a combination of both. Temporary plots can be used to obtain estimates of the current state of the forest, while permanent plots or a mixture of permanent and temporary plots are prerequisites for obtaining estimations of change over time (Picard *et al.*, 2010). Estimation of change is a complex challenge. There are three major types of temporal changes in forestry: (i) change conforming to the expected progression of living and dead material in a forest during the period of interest (e.g. volume increment of living trees); (ii) unexpected biotic or abiotic disturbances (e.g. mortality due to insect, snow, wind, fire, etc.); and (iii) forest management activities (thinning, harvesting, planting, seeding, etc.). Each category operates at different temporal

and spatial scales. Given the multivariate nature of forest resources, and the wide range of rates and modes of change, it follows that the efficiency of most sampling designs for estimation of change can be highly efficient for one attribute of change (e.g. net volume increment), yet inefficient for capturing other types of change (e.g. rates of deforestation, volume destroyed by fire, insect mortality). Few practical designs are efficient for capturing change in sensitive but small subpopulations (e.g. number of specimen of a rare or possibly endangered species) (Christman, 2000; Magnussen *et al.*, 2005). To adequately capture changes related to abiotic and biotic disturbances and to forest management practices, it is common to conduct a census of correlated ancillary variables via remote sensing at the start and the end of the period covered by the change estimate(s) (Coppin *et al.*, 2004; Stehman, 2009; Tomppo *et al.*, 2008).

Change estimates are frequently evaluated against expectations or a set of targets, and estimates of the precision of the change estimate are important in this situation. When the change is estimated from a combination of field observations and remotely sensed ancillary variables, estimators of change and their precision can become very complex, and the actual estimation may require the assistance of a statistician (Stehman, 2009). Unless it can be argued on statistical grounds that an estimate of change is unbiased, bias should be accepted as a potential issue.

The simplest change equation is for a trait *Y* observed at time *t* and then again at some future time $t + \Delta_t$. Here $Y_{t+\Delta t}=Y_t+\Delta Y_{\Delta t}$ where Y_t is the initial measurement at time *t*, $Y_t +_{\Delta t}$ is the future measurement at time $t + \Delta t$, and $\Delta Y_{\Delta t}$ is the change in *Y* from time *t* to time $t + \Delta t$. The variance of the estimate of $\Delta Y_{\Delta t}$, depends on the type of plots (or mixture of plots) used for the data collection. Any correlation between measurements at two points in time must be accounted for when estimating the variance of a change.

Continuing this simple example, the estimate of change is $\Delta Y_{\Delta t}=Y_{t+\Delta t}-Y_t$. In this case, the variance of the change estimate is equal to:

$$var(\Delta Y_{\Delta t}) = var(Y_t) + var(Y_{t+\Delta t}) - 2\rho(Y_t, Y_{t+\Delta t})$$
$$\sqrt{var(Y_t)var(Y_{t+\Delta t})}$$

where *var* denotes a variance and *cov* a covariance, and ρ is a correlation coefficient (between the original and future measurements). A strong positive correlation reduces the variance of a change measurement. When a sample selection has been derived with an unequal probability sampling design, the analyst must take into account that these probabilities may have changed over time (Roesch, Green and Scott, 1993).

As discussed in section 7 (p. 124), if the above change estimation involves the use of quantities that are predictions of expected values from one or more models, then it will again be necessary to account for the "hidden" errors in Y_t and $Y_{\Delta t}$. This will commonly be the case in forestry. Compounding the issue is the fact that the errors in Y_t and $Y_{\Delta t}$ often tend to be correlated. Additional complications arise when the method (protocol/process) for obtaining Y_t differs from that of $Y_{t+\Delta t}$ The assistance of a professional statistician may be called for.

8.1 Estimating change using remeasured permanent plots

Permanent plots refer to forest sampling locations that are monumented or otherwise uniquely identified and remeasured at different points in time (Köhl, Magnussen and Marchetti, 2006: 144).

From a statistical and data analysis perspective, the major advantage to permanent plots is improved precision of estimates of change due to a typically strong correlation of sampling errors (see the above expression for the variance of a change). Higher data quality

may also materialize from additional attention and quality control. Finally, permanent plots permit inference regarding cause and effect (Augustin *et al.*, 2009). For undisturbed and carefully measured permanent plots the correlation between subsequent measurements tends to be both positive and relatively strong, which, as outlined above, lowers the variance of an estimate of change. Yet the correlation between successive measurements can deteriorate quickly with the length of a measurement interval and disturbances (e.g. fire, wind, snow, drought, forest management interventions). High data quality facilitates error checking in current data and scanning for anomalies in past data.

8.2 Estimating change using temporary plots

Temporary plots offer a maximum of flexibility: independent surveys can be established at different times, with plots only measured at one time. Since surveys at different times are taken on different plots, the advantage of the above-discussed positive correlation of plot-specific observations at time t and $t+\Delta t$ no longer exists (there is no natural pairing of the two sets of observations).

Individual trees on temporary plots are usually measured more quickly and with less precision than those on permanent plots, reducing the precision of the estimates and the resulting estimate of change. Less precise observations will also make it more difficult to spot outliers and anomalies in the data (Cerioli, 2010). A lower data precision can, to a degree, be offset by the use of a greater number of temporary plots, but the final trade-off depends, in a complicated way, on where and how errors enters the observations and on the assumed model behind the observations (Carroll, Ruppert and Stefanski, 1995).

Self-study exercises

Abbreviations:

B = basal area (of a tree or trees in a plot)
BAF = basal area factor (in Bitterlich sampling)
BEF = biomass expansion factor
CWD = coarse woody debris
D = stem diameter of a tree at a given reference height (typically 1.3 m)
H = tree height
Lidar = light detection and ranging (aka laser scanning)

Exercise 1.

Your task is to estimate total stem volume for a fixed area plot in an inventory. The example assumes that there is only one species in the plot, and that a single volume equation is adequate.

The area of the plot is 600 m^2.

You have measured the diameter (D) at breast height for all trees with a height greater than 1.3 m.

You have also measured the height of eight trees for the purpose of constructing of a height-diameter model and the prediction of height for trees with no measured height.

Trees selected for a height measurement are highlighted (bold) in the data given below.

There are 42 trees in the plot. The diameter (*D*) at breast height was measured to the nearest 0.5 cm, but the data were rounded to the nearest 2-cm class. The recorded values of *D* are as follows:

D = {18, **18**, 20, 22, 22, 22, **22**, 22, 22, 24, 26, 26, 28, 28, 28, 28, **28**, 28, 28, 30, 30, **30**, 30, 30, 30, 30, **30**, 30, 30, 30, 30, **30**, 32, 32, 32, 32, **32**, 32, 34, 34, 36, 36}

Q1.0 Compute the basal area (*B*) in square metres per hectare from the given data of *D*

and plot size (give the result to the nearest 0.1 m^2).

Q1.1 Has the rounding of *D* introduced a bias in the estimate of *B*?

Q1.2 What is the magnitude of the relative bias (i.e. bias in percent of the estimate of *B*) introduced by rounding measurements of *D* in *B*? Pick the most appropriate answer from the following list of relative bias: −5%, −2%, 0%, 2%, 5%.

Heights of the eight measured trees were measured to the nearest 10 cm, but only recorded to the nearest 0.5 m. The height data were:

H ={26., 27.5, 29.5, 30., 30., 31., 31.5, 31.5}

To predict the expected height (*eH*) for trees with no height measurement you opt for the following height-diameter model:[1]

eH = *b*0 +*b*1*loge[*D*]

Estimate via ordinary least squares the regression parameters *b*0 and *b*1.

Q1.3 Do you think the rounding rule applied to *D* has an effect on your estimates of *b*0 and *b*1?

With the estimates of *b*0 and *b*1, compute the expected height of all plot trees (call them *eH*; notice: the expected height of a measured tree is the measured height). Round all expected heights to the nearest 0.5 m.

Compute the expected total stem volume of the 42 trees (*eV*) using the following volume-equation (*D* in cm, *H* in m): [2]

eV = 3.03 * 10-5 * *D***1.7 * *eH***1.3

Round each tree's volume estimate to the nearest 0.02 m^3.

Q1.4 In your opinion, does the above rounding rules for *D* and *H* introduce a bias in the estimate of the mean tree height (i.e. mean of *eH*)?

Q1.5 Does the rounding of *D* and *H* introduce a bias into the expected total volume (*eV*)?

Exercise 2.

You are tasked with estimating the total above ground biomass for a species AA in a newly inventoried forest. The inventory provides you with the diameter at breast height for all trees of species AA with a height larger than or equal to 1.3 m. You have identified the following four above ground biomass (AGBM in kg oven-dry mass) equations as suitable candidates.[3]
D is diameter at breast height (in cm).

EQ1: AGBM = 0.0983 * *D***2.3773
EQ2: AGBM = 0.0617 * *D***2.5328
EQ3: AGBM = 0.0842 * *D***2.5715
EQ4: AGBM = 0.0629 * *D***2.6606

To help you decide which equation is most suitable, you have estimated AGBM for ten trees sampled at random from the inventory sample.

The diameter (*D* cm) and above ground oven-dry biomass (AGBM kg) of your ten trees are as follows:

Tree no.	*D* cm	AGBM kg

1 Taken from Loetsch, Zöhrer and Haller, 1971, *Forest inventory*, Vol. 2. BLV, p. 130.
2 Adapted and modified from Brackett, 1973, *Notes of tarif tree volume computation*. State of Washington, Department of National Resources. Resource Management Report No. 24. Converted to SI units.
3 From Ter-Mikaelian and Korzukhin, 1997, Biomass equations for sixty-five North American tree species, *Forest Ecology and Management*, 97(1): 1–24.

1	3.1	1.52
2	9.3	26.26
3	11.2	41.26
4	13.6	69.10
5	13.9	70.44
6	15.3	91.72
7	19.4	161.68
8	28.9	493.56
9	36.3	840.06
10	40.0	1115.20

Q2.1 Based on this information, which of the above four equations appears to be most suitable for use? Explain your choice of equation.

Exercise 3.

Your task is to estimate total tree stem volume of trees in the NFI plots of your country. You have made observations of diameter at breast height (D) and height (H) of all trees in all measured NFI plots. For species AA, BB and CC you are using volume equation models that can estimate the total stem volume from H and D. However, for species DD you do not have a model for volume estimation. For this exercise, assume that you have only observed these four species in your NFI plots. How would you go about estimating volume for species DD in this situation? Please explain your suggested approach. What factors might prevent you from reaching a decision? In the event that no decision is possible, what additional information might be required to reach a decision and estimate the volume for trees of species DD?

Exercise 4.

You are part of an NFI/NFA team responsible for taking field measurements in NFI plots. Stakeholders of the NFI are keenly interested in estimating ecosystem carbon content. A funded request is put forward to select data in the NFI plots to estimate carbon content in forest floor litter. How would you respond to this request? If a decision is taken to meet this request what field procedure would you recommend?

Exercise 5.

An NFA client/stakeholder has asked you to make predictions of total above ground biomass of live trees within a 1000 km^2 region with approximately 60 percent forest cover. There are only 25 NFI plots in this region. The biomass estimates from these 25 plots are highly variable. A direct estimate of biomass for the region based on the 25 samples would have a very low precision. You have access to national archives of remotely sensed data. What course of action would you embark on in this situation?

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Scenarios

Tuula Packalen

THIS CHAPTER DISCUSSES THE FOLLOWING POINTS:

- The utilization of scenarios in the design of national forest strategies and policies in different regions.
- New concepts such as supply-driven and demand-driven scenario types as well as research-initiated and policy-targeted scenario modelling types.
- Typical scenario modelling process with linkages to NFAs and NFPs (national forest programmes).
- Linkages to different scenario tools and case studies.

Abstract

Forests are expected to provide multiple products and services for current and future generations. National Forest Monitoring and Assessment (NFMA) produces information on current forest resources and their changes. Future forest resources and their potential use are more difficult to estimate because they depend both on current forest resources and their management. Correspondingly, decisions concerning forest management strategies affect future forest resources, products and services.

Scenarios are useful tools for making strategy options and their consequences more transparent for participatory and collaborative decision and policy-making processes, such as national forest programmes (NFPs). Several different approaches and tools exist for scenario modelling at national, sub-national and local levels, including trend extrapolation, matrix models, and stand-level or regional-level forest dynamics models, which are often used together with forest sector models. In the future, the compatibility of NFPs and their reference scenarios with sustainable development, international agreements and global markets will become increasingly important. FAO therefore supports harmonization through, for example, Global Forest Resource Assessment, national forest monitoring and assessment projects, the National Forest Programme Facility and the UN-REDD programme.

1. Introduction

Both developed and developing countries have encountered challenges with regard to sustainable forest management (SFM).

SFM covers a wide variety of economic, ecological, social and cultural factors. In addition to industrial round-wood and fuel-wood, non-timber forest products and the role of forests in protecting biodiversity and water resources or providing facilities for recreation and carbon dioxide storage, should also be taken into account. To compensate, protective measure payments for ecosystem services (PES) have been introduced.

Consequently, there may exist several alternative combinations of forest products and services and corresponding management strategies for a given country. Large-scale industrial plantations, small-scale community forest plantations, agroforestry, strict forest protection, forest rehabilitation and ecosystem approaches for multiple-use forest management, or any combination of these, may be optional management strategies for many developing countries. At the same time, developed countries may consider different national strategies to utilize the potential of forests in climate change mitigation, such as the amount of carbon that should be stored in harvested wood products and growing stock.

The SFM objectives, including different forest products and services together with the corresponding forest management strategies and policy measures, should be defined collaboratively with the stakeholders and decision-makers who will be involved afterwards in implementation. This kind of participatory process, which aims to promote sustainable and multipurpose forest management through collaboration, is referred to as a national forest programme (NFP).

The role of an NFP in a given country is to formulate activities and policy programmes towards the desired future in terms of sustainable use, conservation and development of forests. Because future forest resources and their potential use depends on adopted forest management strategies, the evaluation of alternative strategies and their consequences in terms of future forest products and services is an important part of participatory and collaborative decision and policy-making processes. Scenarios are useful tools to make strategy options and their consequences more transparent. They can be used, for example, to determine the impacts of different management strategies, such as shifts in land-use, establishment of plantations and investments in fertilization programmes, or to analyse the impacts of different utilization rates on future wood resources.

Intergovernmental dialogue has recognized the essential role of NFPs in addressing forest sector issues. To this end, FAO established in 2002 an NFP facility to assist countries in developing and implementing NFPs that effectively address local needs and national priorities, and reflect internationally agreed principles (e.g. country leadership, participation and integration of cross-sectoral issues). An ideal NFP is a cyclical process split into four phases: analysis, policy formulation and strategic planning, implementation, and monitoring and evaluation. *National Forest Monitoring and Assessment* (NFMA), also supported by FAO, plays an important role in the analysis and monitoring stages. In the policy formulation and strategic planning stage, additional future-oriented tools such as scenarios are needed.

The objective of this chapter is to introduce different scenario modelling approaches, outline a typical scenario modelling process with linkages to NFMA and NFP and, finally, discuss some future challenges of scenario modelling. The chapter focuses on the potential of scenarios for the design of national forest strategies and policies.[1]

2. Scenario modelling approaches

A number of different approaches and tools are used in scenario modelling. Based on the driving force of the model, scenarios can be categorized as either *supply-driven* or *demand-driven*. In supply-driven scenarios, the target of modelling is to analyse the impact of change factors on supply of forest resources. Supply change factors may include afforestation, strict forest protection or rehabilitation programmes. In demand-driven scenarios, the modelling aims to analyse the impacts of use of resources on future forest conditions. Demand change factors may

1 For more information on spatially explicit landscape modelling or growth and yield modelling, see www.cifor.org/online-library/research-tools/flores.html and Weiskittel *et al.* (2011)

include increasing use of wood-based energy and the establishment or closing of a pulp and paper mill.

Supply-driven scenario modelling covers:

- Statistical trend extrapolation of forest resources
- Predictive models that forecast transition of a forest class into another class among a matrix of classes (e.g. EFISCEN)[2]
- Forest dynamic simulation models applied to inventory units (stands, trees) or their aggregates (e.g. OSKAR).[3]

Some models can be used for both supply-driven and demand-driven analysis, such as MELA in Finland[4] and Heureka in Sweden.[5] MELA and Heureka have two main components: a stand-level simulator and a region-level optimizer. The simulator generates multiple development paths for stands. The optimizer can be used to search for combinations of paths that fulfil the demand in terms of future forest resources, products and services. The approach and tools have been designed for boreal conditions where forests are managed as stands. In temperate forests with uneven aged and multiple species stands, stand simulators or diameter-volume state transition models are used (e.g. Buongiorno *et al.*, 1995). In tropical forests where hundreds of tree species appear, tree-level or species-group models are required for the simulation of dynamics and selective cutting (Macpherson *et al.*, 2010).

It is also possible to integrate supply-driven forest resource scenario models with demand-driven forest sector models. Examples include the integration of:

- EFISCEN and EFI-GTM, used for the European Forest Sector Outlook Study (EFSOS)[6]
- OSKAR and FASOM, used by IIASA[7]
- Atlas and TAMM, used by USDA Forest Service for RPA until 2000[8]
- MELA and SF-GTM, used by Metla to support the National Forest Programme.[9]

Scenario modelling can be *research-initiated* or *policy-targeted*. Research-initiated scenario modelling can be divided further into ad hoc analysis addressing specific questions (e.g. Alig *et al.*, 2001; Eid, Hoen and Økseter, 2002; Eriksson, Sallnass and Stahl, 2007) or systematic work carried out at regular intervals (e.g. Adams and Haynes, 2007).

The most common model to capture trends at regular intervals is wood resource balance (WRB) comparing felling (removal or drain) against increment of growing stock. The utilization of wood resources has been considered sustainable as long as felling remains smaller than increment (see e.g. Forest Europe, 2007, Indicator 3.1). A static measure such as WRB works best for so-called normal forests, where a forest is composed of even-aged fully stocked stands representing a balance of age classes.

In conditions where age-class distribution is skewed, other measures are recommended. For example in Finland, three different measures are calculated regularly[10] for the 10-year period, starting from the most recent national forest inventory year and comparing with the recorded removals of the preceding 10-year period: (i) potential cut, (ii) removals maximizing net present value and (iii) maximum sustainable yield. *Potential cut* defines the maximum removals from the forest and scrubland when forestry guidelines are followed and all restrictions for forest management due to protection and multiple use of forests are taken into account. *Removals maximizing net present value* also take into consideration the profitability of felling. Some forests are set-aside as non-profitable and

2 See www.efi.int/portal/virtual_library/databases/efiscen/

3 See www.iiasa.ac.at/Research/GGI/docs/oskar.pdf

4 See http://fp0804.emu.ee/wiki/index.php/MELA

5 See http://fp0804.emu.ee/wiki/index.php/Heureka

6 See http://timber.unece.org/index.php?id=55

7 See www.iiasa.ac.at/Research/GGI/docs/index.html?sb=8

8 See www.fs.fed.us/research/rpa/what.shtml#2010RPA

9 See www.metla.fi/julkaisut/workingpapers/2008/mwp075.pdf

10 See p. 179 of www.metla.fi/metinfo/tilasto/julkaisut/vsk/2009/vsk09_04.pdf

some felling operations are postponed for later periods because of their value increment. *The maximum sustainable yield* defines the maximum removal that can be cut without decreasing future potentials.

The role of policy-targeted scenario modelling as a part of NFP is to forecast future forest resources, assess resource use potentials, and evaluate optional strategies and policies. Model-based scenarios that predict what will happen as a consequence of different policies or strategies are used, for example, in Nordic countries (e.g. the Finnish National Forest Programme[11] and the Swedish Forest Impact Analyses)[12] and in the United States (Resources Planning Act Assessment).[13] In Finland, policy-targeted scenario modelling has been carried out at national (e.g. Kärkkäinen *et al.*, 2008), sub-national (e.g. Nuutinen *et al.*, 2009) and local (e.g. Nuutinen *et al.*, 2011) level.

3. Scenario modelling process

Scenario modelling can be used to address both slow and abrupt changes. Slow changes include, for example, the natural development of forest resources, and can be predicted using simple forest dynamics simulation models. Abrupt changes, such as decisions on policy measures, usually have complex impacts on forest resources as well as socio-economic effects. Therefore, the modelling requires explicit definition of the interrelationships between the different processes and actors, and quantification of system parameters other than just those concerning forests.

Typical steps in the scenario modelling process relating to NFP and supported by NFMA include (see Figure 1):

- Collection of background information about the current situation, state and trends of:
  - forest resources covering round-wood, fuelwood, non-timber forest products, biodiversity, water, recreation, carbon dioxide storage, etc.
  - land use (including competing land-uses and their future pressure on forest land)
  - forest use
  - removal, consumption and markets of forest products
  - legislation and policies
  - stakeholders and their responses to policy measures
  - reference scenarios (e.g. global market scenarios)
- Collection of information about national objectives
- Design of alternative strategies or policies and related actions or measures
- Prediction (simulation, model-based scenarios) of what will happen to forest conditions and the potential use of forest resources under different alternatives; estimation of parameter values for current and future forest resources, products and services
- Evaluation of the consequences of alternatives
- Consensus-building, sometimes an iterative process, with the design of alternatives and consequent steps
- Implementation, and
- Monitoring of implementation to obtain feedback for the next scenario round (e.g. collecting information about stakeholder response to policy measures).

For model-based scenarios, NFMA is the essential source for data on forest resources (usually aggregated data on age-volume classes or diameter distribution) and growth estimates. Furthermore, NFMA data can be used for modelling forest parameters such as biomass or carbon content. Statistics on felling or afforestation activities can be utilized if business-as-usual scenarios are modelled.

11 See www.mmm.fi/attachments/metsat/kmo/5Ad5R83tH/KMO2015engl.pdf

12 See www.skogsstyrelsen.se/Myndigheten/Skog-och-miljo/Tillstandet-i-skogen/Tillgangen-pa-skog/

13 See www.fs.fed.us/research/rpa/what.shtml#2010RPA

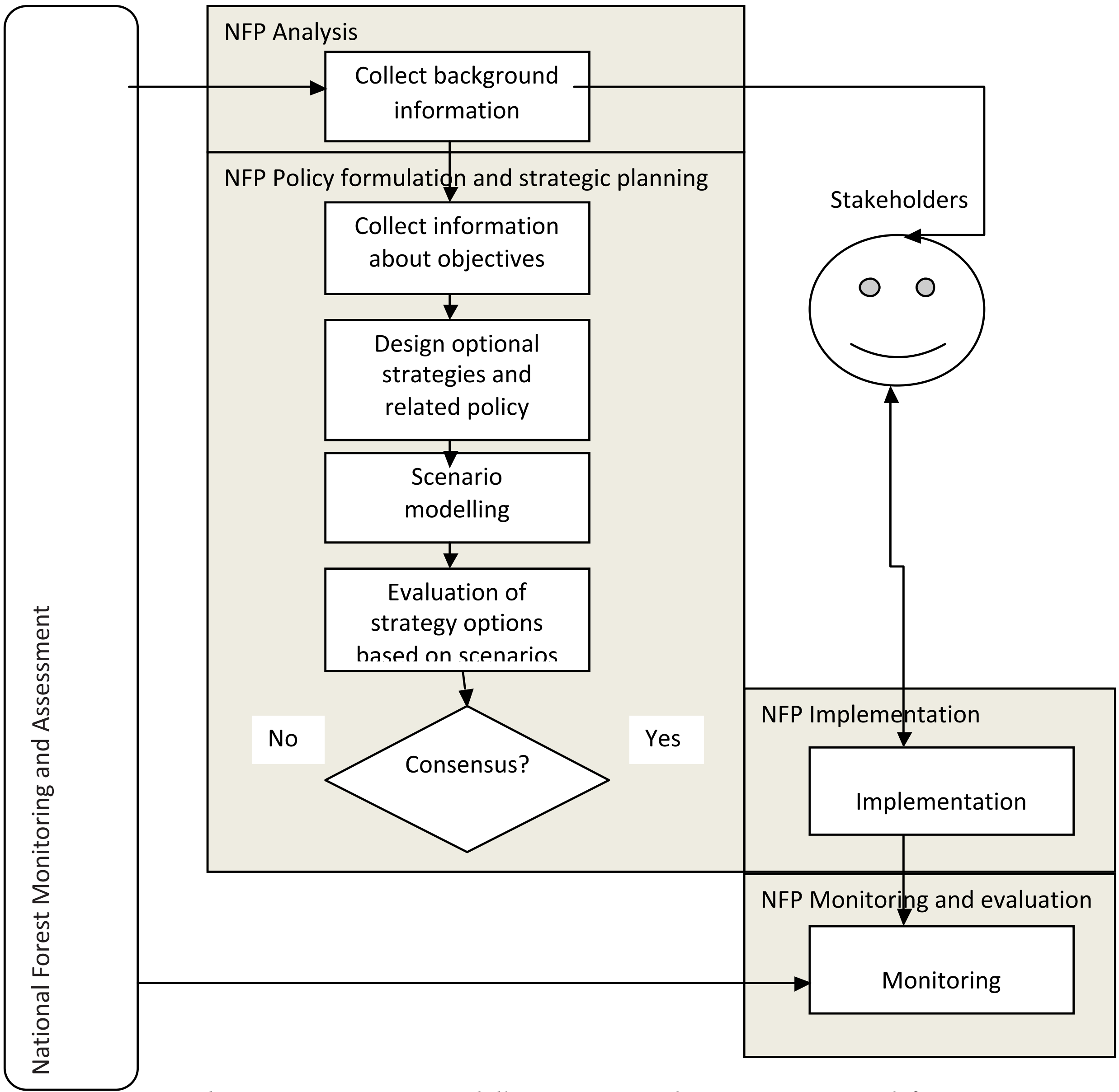

Figure 1. Typical steps in scenario modelling process relating to a national forest programme (NFP) and supported by National Forest Monitoring and Assessment (NFMA).

4. Discussion

Scenario modelling has been applied in national forest strategies or policy processes mainly for boreal and temperate forests. However, the emergence of international mechanisms such as REDD+ (see UN-REDD Programme) has increased interest in scenario modelling for tropical forests. For example, the strategic decisions concerning management options such as large-scale industrial plantations, small-scale community forest plantations, agroforestry, strict forest protection, forest rehabilitation and ecosystem approaches for multiple-use forest management, or any combination of these, would benefit from analytic and quantitative assessment of different strategies in terms of carbon storage.

A major challenge for scenario modelling is to support national strategies and policies in the context of international agreements and global markets. In this context, the compatibility of national scenarios with regional or global reference scenarios becomes of increasing importance. A partnership programme based on country reports, such as Forest Europe or FAO's Global Forest Resource Assessment

(FRA), offers motivation and a potential framework to harmonize national forest scenario modelling. In Europe, the bottom-up approach based on national forest scenario modelling would complement the top-down process applied in EFSOS 2011, similar to the way in which the North American Forest Sector Outlook Study (NAFSOS) is integrated with the USDA Forest Service RPA. FAO supports such processes through National Forest Monitoring and Assessment projects and the National Forest Programme Facility.

Self-study exercises

1. What is the role of scenario modelling in the preparation process of a national forest programme (NFP)?
2. What is the role of National Forest Monitoring and Assessment in the NFP preparation process, in particular in relation to scenario modelling?
3. List trends and other potential change factors affecting the *demand* for wood and other forest resources in your country.
4. List trends and other potential change factors affecting the *supply* of wood and other forest resources in your country.
5. What types of scenarios, approaches for scenario modelling and actual scenario models (software tools) would be applicable for your country?

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Examples of scenario modelling as part of policy and strategy processes:

Finnish National Forest Programme: www.mmm.fi/attachments/metsat/kmo/5Ad5R83tH/KMO2015engl.pdf

Swedish Forest Impact Analyses: www.skogsstyrelsen.se/Myndigheten/Skog-och-miljo/Tillstandet-i-skogen/Tillgangen-pa-skog/)

United States Resources Planning Act Assessment: www.fs.fed.us/research/rpa/what.shtml#2010RPA

European Forest Sector Outlook Study (EFSOS): http://timber.unece.org/index.php?id=55

Examples of scenario models:

EFISCEN: www.efi.int/portal/virtual_library/databases/efiscen/

OSKAR: www.iiasa.ac.at/Research/GGI/docs/oskar.pdf))

MELA: http://fp0804.emu.ee/wiki/index.php/MELA

Heureka: http://fp0804.emu.ee/wiki/index.php/Heureka

FAO and Forest Europe linkages

GFRA: www.fao.org/forestry/fra/en/

NFMA: www.fao.org/forestry/nfma/en

NFP Facility: www.nfp-facility.org/en/

UN-REDD Programme: www.fao.org/climatechange/unredd/en/

State of Europe's Forests: www.foresteurope.org/?module=files;action=file.getfile;id=485

The Food and Agriculture Organization of the United Nations (FAO) has been monitoring global forest resources for many decades, through its Forest Resources Assessment (FRA) programme and by providing direct country support to establish national forest monitoring systems.

In an era where interest in the world's forests has grown to unprecedented heights, FAO's commitment remains strong. In recent years FAO Forestry Department has made significant progress in its ability to directly support countries in their efforts to assess the extent, quality and importance of their forestry resources. Country support is delivered through a variety of means which together comprise a tool-kit to facilitate countries' capacity development.

This knowledge reference (KR) for national forest assessments is a further tool to be used for country support with the objective of giving countries autonomous and continuous capacity to monitor their own forests.

ISBN 978-92-5-108832-6

9 789251 088326

I4822E/1/07.15

www.fao.org/forestry/fma