National Forest Monitoring and Assessment

Technical Review of FAO's Approach and Methods for National Forest Monitoring and Assessment (NFMA)

by
Erkki Tomppo and Krister Andersson

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N F M A

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Forests are crucial for the well being of humanity. They provide foundations for life on earth through ecological functions, by regulating the climate and water resources and by serving as habitats for plants and animals. Forests also furnish a wide range of essential goods such as wood, food, fodder and medicines, in addition to opportunities for recreation, spiritual renewal and other services.

Today, forests are under pressure from increasing demands of land-based products and services, which frequently leads to the conversion or degradation of forests into unsustainable forms of land use. When forests are lost or severely degraded, their capacity to function as regulators of the environment is also lost, increasing flood and erosion hazards, reducing soil fertility and contributing to the loss of plant and animal life. As a result, the sustainable provision of goods and services from forests is jeopardized.

In response to the growing demand for reliable information on forest and tree resources at both country and global levels, FAO initiated an activity to provide support to national forest monitoring and assessment (NFMA). The support to NFMA includes developing a harmonized approach to national forest monitoring and assessments (NFMA), information management, reporting and support to policy impact analysis for national level decision-making.

The purpose of the NFMA initiative is to introduce countries to an alternative approach designed to generate cost-effective information on forests and trees outside forests, including all benefits, uses and users of the resources and their management. Special attention is placed on monitoring the state and changes of forests, and on their social, economic and environmental functions. Another main objective is to build national capacities and harmonize methods, forest related definitions and classification systems among countries.

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EXECUTIVE SUMMARY

The purpose of this report is provide a scientific examination of the methodological aspects of FAO's National Forest Monitoring and Assessment (NFMA) program and to explore alternative ways of organizing the programs data collection procedures. The report starts out with a brief discussion of why NFMAs are important. We then introduce our main evaluative criteria that we use throughout the report to examine the soundness of the methodological decisions made by the FAO and its partner countries. We pay particular attention to the decisions regarding sampling design and the use of statistical inference in data collection and estimation phases of the NFMA. Grounded in our technical examination of the FAO approach, we end the report with a discussion of a series of recommendations for how FAO's Forestry Department may make its support to NFMA programs even more effective. .Our main recommendations include:

- Continue with general NFMA approach that emphasizes country-defined goals and integrated social and biophysical data collection;

- Make household surveys developed under the ILUA programs in East Africa a permanent part of a multi-source suite of methods for data collection. The increment in costs for doing so are by offset by improved levels of precision and accuracy for the estimation of socioeconomic parameters;.

- Explore and experiment with alternative sampling designs and plot layouts in interested countries. The results from our sampling simulation study show that, compared the NFMA design with alternative designs, the NFMA sampling design can be further improved. We urge the Forestry Department to invest in experimentation and learning from new and alternative methodological approaches to data collection in the NFMA. This, we are convinced, will enable FAO to become even more responsive to member countries' needs and priorities;

- Make better use of existing data for both biophysical and socioeconomic variables in the sampling design. This has the potential to achieve important efficiency gains;

- Reinforce existing quality control systems for data collection for all variables, but especially for socioeconomic and institutional data since these rely largely on indirect measurement techniques;

- Make sure that the estimators of the biophysical and socioeconomic parameters take into account the employed sampling design and plot configuration, and

- Invest more in country-led analysis of the collected NFMA data, especially as it relates to the country's pronounced policy needs.

We further develop these and other ideas for future directions in the report. By addressing these concerns, we believe FAO's support to the NFMA will be in a stronger position to adapt to shifting demands for country-level data about forest and forest use.

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A. Justification: Why are NFMA programs important?

Forests are complex natural systems that produce multiple goods and services, sometimes hundreds—each of which has its own set of inputs and outputs in its production. And each product and service from any given forest may benefit hundreds of individuals at different scales of society and with different needs. Such complexity challenges any attempt to create simple streamlined policies to manage forests effectively. Because of the social and natural uncertainties associated with forest governance, forest policies need to be adaptive.

To be effective, forest policies must adjust to lessons about how past policies have performed, especially with regards to how they deal with changing natural and human conditions, To create such adaptive policies, however, require a continuous flow of reliable information about how forests are changing overtime and what role policies play in such a dynamic process. To make informed decisions about how current policies may be modified, policy makers need accurate and precise information about how these policies influence the condition of forests and trees.

The problem is that few countries generate systematic data on the changing characteristics of their forest resources and trees outside forests (TOF), and even fewer countries collect and analyze information on the factors that help determine the effectiveness of public policy in supporting sustainable forest management. FAO estimates that only 15 % of the world's developing countries actually carry out regular field-based forest inventories (FAO, 2005). The reasons for this situation are largely related to the perceived high costs of forest inventories and that countries have chosen to prioritize other areas of public investments.

The 2005 COFO recognized this limitation and consequently asked the FAO to "strengthen its activities in the area of monitoring, assessment and reporting on forests and intensify assistance to countries for activities in this area" (ibid: 9-59). FAO was also asked to "assist countries to better incorporate forestry in poverty reduction strategies, to enhance forest law enforcement…and to strengthen capacity for conducting national forest assessments and building forest information systems" (ibid: 9-58).

FAO's support to national forest inventories and assessments aims to "contribute to the sustainable management of forests and TOF by providing decision makers and stakeholders with the best possible, most relevant and cost-effective information for their purpose at local, national and international levels" (FAO, 2002) In the National Forest Monitoring and Assessment (NFMA) program, FAO assists countries that have requested support in developing baseline information from statistically verifiable data on the state of the country's forestry resources, their uses and management. More specifically, countries that collaborate with FAO in implementing this approach generate policy-relevant information based on a broad set of variables ranging from biophysical characteristics of the resource to socioeconomic aspects of resource usage.

Increased investments in NFMA programs in developing countries have never been more urgent. There are both national and international policy processes that are in desperate need of better data and analysis on the changing role of forests in human development efforts. At the national level, the information and knowledge that are generated from such assessments may be used for strategic decisions related to how public and private investments might be directed to increase the flow of forest-derived benefits to society at large. Consider the role played by national forest inventories in Germany and Finland in the past 25 years.

In Germany, the first NFI in 1986-1990 produced very surprising results, the estimate of the volume of the growing stock increased significantly from that based on the earlier management inventories. Changes in public forest policy were made.

In the Nordic countries, NFIs have a long history. Particularly in Finland, but also in Sweden and to some extent in Norway, forest industries have played and still play an important role in the national economies. NFIs an essential component in what called forestry cluster, and are employed both in strategic planning of forest policy, forest management and in planning forest industry investments.

At the national level of decision making, there are several central questions that decision makers are not able to answer without good national forest inventory data, such as

- Are there untapped potentials in the sector?
- What is the potential economic, social and ecological contribution of forests to society?
- What are the economic, social, and economic tradeoffs between forests used for conservation, commercial management and/or subsistence use for rural people?

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At the international level, international forest policy actors need to be informed about how the world's forest resources change over time and how these processes affect our collective ability to mitigate climate change, protect biological diversity, and to enhance the potential for forests to contribute to poverty reduction and food security. The specific questions that decision makers at this level would not be able to answer without reliable and valid NFMA data include

- How do forests affect climatic change and how does such change affect forests?
- How do individual countries' efforts to govern forests in a sustainable way add up at the global level? What is the net effect?
- What opportunities exist for international transfers of human, financial and infrastructure capital to augment the role played by forests in the quest for the millennium development goals?

Realizing that traditional National Forest Inventories (NFIs) could not provide answers to many of these questions at both national and international levels, FAO designed a new approach to Forest Assessments and Monitoring: The FAO program on National Forest Monitoring and Assessment was born. FAO developed a new and broader data collection protocol that allowed for more policy-relevant information to be collected and analyzed. To this end, the evolving FAO approach to NFMA incorporated many of the traditional NFI forest and tree measurements, but in addition, it also included systematic data on trees outside forests, identification of forest products and services derived from sample areas, property rights and policies associated with such products and services, as well as the socioeconomic and institutional characteristics of forest use and users.

One of the potential advantages of this approach is that the inclusion of data on the human use of the forest resources surveyed allows national forest policy analysts and decision makers develop knowledge about the factors that affect the changing forest condition in a country, something that traditional NFIs could not deliver. Such knowledge makes it possible to monitor the effects of previous policy efforts and to develop alternative policy instruments that are more effective in achieving the national forest policy goals.

As external evaluators we find that FAO's support to NFMA is extremely important as it clearly meets unmet needs for field-based forest monitoring and assessments in developing countries. At the same time, because of its innovative orientation, ambitious scope, and relatively short history it is important to make periodic evaluations of how the approach and FAO's support to it may be adjusted and made even better. We have written this report with the hope that it will contribute to this continuous learning process as well as to the further development of the FAO's methodological approach to National Forest Monitoring and Assessment.

B. Introduction: General Principles for National Forest Assessments

B.1 Basic principles in planning an inventory or assessment both for biophysical and Socioeconomic parameters

We first recall some general principles and phases which are addressed in planning a forest inventory for a country either with an existing inventory or without any inventory. Some of these principles could be more relevant for more advanced inventories than just a first time inventory, e.g., point four below. The following phases are usually taken in planning a forest inventory.

1. Select (decide) the reporting units
2. Select the parameters for which the estimates are made
3. Explore the target level for the accuracy and precision, given demands by the users and the constraints in the resources, technical capacity (the method should match the capacity)
4. Decide the acceptable (maximum) standard error level for the reporting units
    1. for totals
    2. for changes
5. Select the data sources
6. Designing the data collection methods
7. Decide and develop the analysis methods, the availability of the allometric models, volumes, biomass (carbon stock)
8. Select the reporting and dissemination methods and tools
9. Effectiveness in the implementation (making sure the protocol is followed and good decisions are made, requires training, quality control, accountability).

The use of the inventory results affects the solutions to the questions above. Typical examples of the use of the data are:

1. Strategic planning of forestry including monitoring of forestry operations
2. Strategic planning of forest industry
3. Monitoring of statuses of forest environment and biodiversity of forests
4. Estimation of carbon balances of forests.

The scope of forest inventories is becoming wider and information is needed only about forests but about all land uses and land use changes. The monitoring system should provide information also about

5. Land use and land use and land use changes
6. Non-wood goods and services.

Independently of the method and the use of the data, the system should fulfill some basic requirements. Examples are:

1. The method must produce unbiased estimates.
2. The method must produce error estimates.
3. The estimates must be consistent in such a way that when the area increases, the relative error decreases.
4. The method must make a basis for the coming inventories.
5. The output can be utilized in management inventories and in the strategic planning of forestry and forest industries.
6. The inventory data can be employed to calculate annual allowable cut for large regions.

(e.g., FAO-IUFRO. 2007)

The estimates of the following parameters are usually required and produced by reporting units:

1. The areas of land use and land cover classes and the areas of land classes on the basis of UNFCCC LULUCF and Kyoto reporting
2. The areas of forest land by tree species dominance and by age classes (maturity classes)
3. Volume of growing stock by tree species on forest land and forest land sub-categories, and on naturally sparse land
4. Gross growth by tree species or tree species groups
5. Net growth by tree species or tree species groups
6. The volumes of the total drain (=harvest plus natural losses)
7. The carbon pool and carbon pool changes of the five pools given in UNFCCC LULUCF Guidance 2003
8. The areas of accomplished and needed cutting and silvicultural operations on forest land
9. The areas of different damage and disturbance classes on forest land
10. Accurate change estimates for the most important parameters, like areas and volumes.

Many national forest inventories in Boreal and Temperate regions produce estimates for significantly higher numbers of parameters. Examples are soil and site variables, ground vegetation composition and variables employed in assessing the status of biodiversity, e.g., volume and the structure of decaying wood and the extent and quality of key habitats, as well variables related to forest health, like the symptom and causing agent of diseases. Some of these parameter estimates can be skipped for areas outside of potential timber production forests. Some the estimates are not relevant for Tropical forests, e.g., the increment of the volume of growing stock is difficult to assess.

B.2 Basis concepts and principles in statistical sampling applied to a forest inventory

Some concepts and principles employed in statistical sampling are first listed. Most of these concepts are relevant and should be addressed in forest inventory planning.

1. Target population is a set of the elements U_i for which the inference is to be made. Population can be discrete (finite or infinite) or continuous (always infinite, e.g. a real plane).

2. A sample *s* is a subset of the population.

3. Sampling fram is the mechanism which allows to identify the elements in the population.

4. The set of all samples is denoted by *S*.

5. The sampling frame usually determines the selection probability *p(s)* of each sample.

6. Inclusion probability $\pi_i = \sum_{s:\ U_i \in s} p(s)$ of an element U_i, tells the probability that an individual is included in an arbitrary sample. Note that the probabilities can vary and that the most efficient sampling procedures often rest upon unequal probabilities (e.g., Mandallaz 2008, see also Gregoire and Valentine 2007).

7. One basic principle in probability sampling is that each element in the population must have a positive inclusion probability π_i. The inference concerns that set of the elements which have a positive inclusion probability. Note that each sample *s* does not have to have a positive inclusion probability. Important is to take into account the unequal probabilities in the inference. Otherwise biased estimates may as a result.

Two further concepts, related to the area units and relevant when sampling in forest inventory context and planning a forest inventory, could be:

A reporting unit is an administrative or ecological region for which the NFI estimates are calculated and reported. The entire area of a country can be divided into non-overlapping reporting units. The union of the units comprises the entire area of the country. Note that this means stratified sampling.

A design unit is a region in which the same NFI method is applied, including field data and field plot density as well as remote sensing data. The union of the design units is the entire area of the country.

The method development starts with the identification of the reporting units and with setting some acceptable upper limits for the errors of the estimates of core forest parameters, e.g., forest area, forest area change and volume of growing stock. A variation of coefficient for the estimate of forest area and volume of growing stock for an area with a total land are of 10 million hectares could be, for example 1-5 %, or even lower depending on the importance of the area and the purpose of the inventory.

On the basis of the reporting units, the inventory design units are defined. The design units are usually larger than the reporting units.

All path-breaking programs, including FAO's support to NFMA and ILUA (hereafter NFMA programs), face the challenge of balancing demands for adaptation with stability and continuity. This review seeks to provide guidance to the Forestry Department with regards to future decisions regarding several important methodological issues related to the sampling design and statistical framework of the NFMA programs. By addressing these issues—none of which we consider to be fatal flaws—we believe FAO's support program will be able to continue to be responsive to member countries' and partner organizations' demands and maintaining its global leadership position in the area of forest resources assessment and monitoring.

Section C discusses the sampling design for data collection associated with both biophysical and socioeconomic data. Section D assesses the statistical framework of the NFMA program, and basically examines the ways in which statistical inference is used in the products of the NFMA. Each of these sections start by briefly highlighting the many positive characteristics of FAO's methodological approach. We then shift our focus to issue areas that, in our opinion, warrant a more critical examination. We end our review in section E by offering a series of recommendations to the FAO Forestry Department for how they might make the NFMA programs even better.

C. REVIEW OF THE NFMA SAMPLING DESIGN

C.1 Biophysical data

The two main aspects analyzed are the sampling design and to some extent the statistical methods. Particularly, emphasis was put on the sampling design analysis.

C.1.1 A preliminary sampling simulation study

Some alternative inventory designs were compared in terms of the estimated sampling errors and estimated measurement costs for some key forest inventory parameters. The output data from the Finnish multi-source national forest inventory were employed (Tomppo et al. 2008b). The data represent Boreal forests. The data from Tropical countries would have given additional value but were not available. It remains for further investigations to test the relevance of the conclusions in Tropical forests.

The results are briefly cited under this section. The full analysis is given in the Appendix 4 (Tomppo and Katila 2008.)

Two basic plot densities were tested, one corresponding a density with a tract at a crossing of every latitude and longitude, and one that could yield also applicable sub-country level estimates.

Two plot densities and sampling designs for which the measurement costs were calculated were:

1. the error level that corresponds the errors of the design of a grid of 4 km x 4 km of detached plots corresponds. The errors of this design corresponds those of the design and plot configuration employed by UN/FAO in NFMA, except that the tract distances are 1/14 degrees in latitude distance and 1/7 degrees in longitude distance. In fact, this was selected in such a way that its errors are near
2. the error level of UN/FAO NFMA design, i.e., the tract distance is one degree in both directions.

The first group of the designs is called here 'dense designs' and the second group 'sparse designs'. The dense design has been selected in such a way that sub-country level parameter estimates with acceptable sampling errors can be obtained from field measurements.

The different designs, selected after numerous trials with both groups, are:

1. A dense UN/FAO NFMA design, a NFMA tract distances in latitude and longitude are 1/14 and 1/7 degrees respectively.
2. A dense grid of detached plots with intervals of 4 km x 4 km, called here a dense Eurogrid.
3. A dense cluster design, a cluster consisting of 12 plots located on the sides of a half rectangle with a distance of 300 meters apart from each other, and with cluster distances of 10 km x10 km (Non stratified cluster design).

4. A dense stratified cluster design the clusters of the plots as in point 3, but the distances between clusters varied in different parts of the country between 10 km x10 km and 15 km x 15 km (Stratified cluster design). In the final design, the cluster distances by regions were from South to North 10 km, 10 km, 11 km, 12 km, 13 km and 15 km (Figure 2, Appendix 4).
5. A sparse NFMA design, a NFMA tract distance in both latitude and longitude is one degree.
6. A Sparse grid of detached plots with the intervals of 37 km x3 7 km, called here a sparse Eurogrid.
7. A sparse cluster design, a cluster consisting of 12 plots located on the sides of a half rectangle (Figure 2) with a distance of 300~m apart from each other and with cluster distances of 80 km x80 km (Non stratified cluster design).

All the designs have been selected in such a way that in the two design groups, dense and sparse, the error estimates for the parameters 1) forestry land area, 2) mean and total volumes of growing stock (all tree species), 3) mean and total volumes of other broad leaved tree species than birch (representing a rare event) as well as 4) the mean and total volume of saw timber, are about the same magnitude within a density group. The efficiencies can thus be compared in terms of the respective costs only. The volume of saw timber represents in NFMA inventory the trees with a DBH at least 20 cm.

For the cost calculations, it has been assumed that a field crew consists of one plus 2 members for other designs except NFMA design for which the crew size is one plus three members. The needed field crew days and the relative costs to measure the entire country of Finland and covering all land use classes are presented in Tables 1 and 2.

Table 1. The field crew days and the relative costs to measure the entire country of Finland, covering all land use classes, dense designs.

Design	Crew days	Relative time	Relative cost
Stratified cluster design	2773	1	1
Non stratified cluster design	3712	1.39	1.39
Eurogrid	4502	1.68	1.68
NFMA	7712	2.89	3.72

Table 2. The field crew days and the relative costs to measure the entire country of Finland, covering all land use classes, sparse designs.

Design	Crew days	Relative time	Relative cost
Non stratified cluster design	55	1	1
Eurogrid	73	1.32	1.32
NFMA	78	1.41	1.82

The design in which the density of the plots varies depending on the variation of the forests is the most efficient one. The NFMA approach needs resources almost four times as much as the stratified cluster design. It seems that the costs could be reduced to some extent using an alternative sampling design.

Particularly with a higher plot density, the tested alternative designs would be more efficient than the one employed in NFMA. One should note that only methods are presented in Appendix 4, in addition to some examples of the results. The investigation of final sampling designs would need more effort and time.

The basic design with sampling units (tracts) in the crossings of latitudes and longitudes, or on the crossings of some fractions of them, has some advantages. It is simply to realize and can easily lead to (almost) unbiased estimators in large areas when applied in a correct way. A rather big plot size has also often been argued for Tropical forests. These results are to some extent in contradiction with our cost-error studies from Boreal forests. A conclusion is that the efficiency justifications need more investigations and particularly data from Tropical countries. All existing data should be investigated and relevant ones employed in sampling studies.

The method presented in Appendix 4 (Tomppo and Katila 2008) could be employed in the target countries using, e.g., existing land cover data, or creating a preliminary land cover map with a help of remote sensing data. Efficient tools are also semivariogram and spatial correlation calculated for some core variables with relevant field data or multi-source data, see also Section C.3. This type of data could be collected from some smaller areas in test inventories. Although the data does not necessarily fulfill the quality requirements of a forest inventory (e.g. could lead biased estimates), it could be employed in analyzing the differences of the efficiencies of the sampling design when taking into account the limitations of the data.

C.1.2 Further comments on sampling design

Some further sampling design related aspects of NFMA approach are discussed in this section.

A positive inclusion probability of the population elements

As discussed in Section B.2, in theory, all individuals within a sampled population should have a known positive probability of being selected. The inference concerns only the set of the individuals, i.e., a subset of the population, which have a positive probability to be selected in an arbitrary sample (a positive inclusion probability). Strictly speaking, many inventory systems, particularly those who use systematic sample designs, do not follow this principle, e.g., those systems in which the locations of the observations are on some pre-selected places, e.g., on the crossings of the map gridlines. Some inventories employing systematic plot layout, include, however a random component into the location of each plot to respect this rule (USA FIA, 2008).

One could argue that by insisting on establishing NFMA plots at the intersections of latitude and longitude lines only, without randomly selecting the point of origin, the design violates the principle of a positive inclusion probability for each element. No points between these intersections have a positive probability of being sampled. This may seem like a trivial point, and, the field plots of the first inventory in a country can in practice be considered to consist of the elements fulfilling the principle of positive inclusion probability. The locations of the plots may not have in practice a high effect on the estimates or the validity of the system.

The generally known locations, together with widely available GPS navigation instruments include a bigger potential problem. The plots could influence the behavior of forest owner and forest users in the country. They may be reluctant to use forest around the known field sites, or may use the forests around the plots in a way which deviates from the use of the other forests outside of the plots. This behavior could have an impact on the applicability of the field plots in the coming inventories. Both the change estimates and current state estimates could be biased.

A potential bias has been reported in some forest inventories when only permanent plots are employed and the locations are visible or know. For example, in China, inventory consultants observed that people adjusted their harvesting patterns, avoiding harvesting in immediate vicinity of the inventory markings left behind by NFI field crews (Ranneby, 1985). They chose to shift their usage to areas that they knew were not being monitored. A possible different treatment could be avoided by hiding the plot locations and keeping the coordinates unknown.

To avoid critique of the current system—a critique based partly on theoretical speculation, the locations could be randomly shifted to some extent.

Changing area representativeness of the plots

Our second comment is related the design with changing area representativeness of the plots. This property could be used to make the inventory more efficient when it is used intentionally. In the NFMA approach, however, the area representativenesses of the plots are determined on the basis of other aspects than the sampling origin ones. The distance between tracts in East-West direction decreased from the Equator towards North and South. The decrease may also have a minor practical effect on the efficiency of the inventory method, at least when the country is located near the Equator. However, there are examples of countries in which the sample plot density in an efficient system should decrease when the distance from the Equator increases. This problem could also be of a theoretical nature, and seems to have been taken into account by varying the density of the plots by sub-regions with a country. The varying area representativeness should be taken into account in estimation, also in a pure latitude / longitude system, see Section C.1.

Change estimation and LULUCF reporting

The NFMA approach which covers all land classes and consists of permanent field plots have indisputable advantages. The use of permanent plots increase the precision of the change estimates and are widely accepted to be a good basis for any land use change estimation purposes including UNFCCC LULUCF reporting. A thorough land class delineation of the plots supports the use of the plots for land use change estimation.

Our main concerns when using NFMA approach for land use change estimation are those already discussed. The estimates are open for critique concerning the representativeness argument and bias when the plot locations are known. The other comment also relates to the precision of the estimates. The changes which are often small cannot be detected at all, or the sampling errors are very high, when using a rather sparse sampling design. The land area changes compared to the areas themselves are in fact often very small. There are a couple of different methods which can be used for assessing the needed number of field plots (e.g., Czaplewski 2003 and Czaplewski, McRoberts and Tomppo, 2004). Tomppo et al. (1998) also presents some error estimates for Boreal forests in typical forest inventory settings when the areas in question are small. The relative error for an area of a size of 10 000 ha varies from 20 % to 50 % when the error with the same setting for an area of 100 000 ha is about 5 % and for an area of one million hectares about 1 %.

The precision of the change estimates and also other area estimates can be increased by taking a higher number of land use observations. Land use and land use change observations could also be taken when walking between plots if the plots in a tract are more widely distributed, i.e., more far apart from each other than in the current design. These types of observations should not be as expensive as the observations. Some basic growing stock information could also be included in case of forest land.

An efficient way for getting additional observations about land use and change could be measurements on strips or line transects. Easily measurable variables indicating the amount of carbon stocks and the changes of carbon stocks of biomass and soil could be added to these observations. These observations would be valuable for supporting the aims of REDD (see Section C.1.3).

Another way of increasing the cost-effectiveness of calculating estimates would be to combine field data with on data from very high or high resolution satellite image data with an image pixel size between 1 and 10 meters. Sampling is a feasible approach with high resolution data. Note that the use of pure remote sensing is not recommended. Field data are always needed (see Section C.2).

Products (e.g. map form predictions) based medium or high resolution satellite images can be employed with field data in many different ways. The use can be tailored to meet the local needs. One way is to use the predictions for post-stratification of the field plots.

The methods presented in Appendix 4 (Tomppo and Katila 2008) to assess the efficiencies of the sampling designs in estimating the current status of forests can also be employed to assess the efficiencies of sampling designs in change detection estimation.

C.1.3. Reducing emissions from deforestation and forest degradation, REDD

UNFCCC, Conference of the Parties on its thirteenth session, held in Bali from 3 to 15 December 2007 accepted actions aiming to reduce emissions from deforestation in developing countries and proposed approaches to stimulate action, Decision 2/CP.13 (UNFCCC 2008). For instance, COP

> "*Encourages* all Parties, in a position to do so, to support capacity-building, provide technical assistance, facilitate the transfer of technology to improve, inter alia, data collection, estimation of emissions from deforestation and forest degradation, monitoring and reporting, and address the institutional needs of developing countries to estimate and reduce emissions from deforestation and forest degradation;"
>
> "*Requests* the Subsidiary Body for Scientific and Technological Advice to undertake a programme of work on methodological issues related to a range of policy approaches and positive incentives that aim to reduce emissions from deforestation and forest degradation in developing countries noting relevant documents;3 the work should include:
>
> (a) Inviting Parties to submit, by 21 March 2008, their views on how to address outstanding methodological issues including, inter alia, assessments of changes in forest cover and associated carbon stocks and greenhouse gas emissions, incremental changes due to sustainable management of the forest, demonstration of reductions in emissions from deforestation, including reference emissions levels, estimation and demonstration of reduction in emissions from forest degradation, implications of national and subnational approaches including displacement of emissions, options for assessing the effectiveness of actions in relation to paragraphs 1, 2, 3 and 5 above, and criteria for evaluating actions, to be compiled into a miscellaneous document for consideration by the Subsidiary Body for Scientific and Technological Advice at its twenty-eighth session;" (UNFCCC 2008).

In practice this means a reliable system for land use and land use change estimation including the changes in carbon stocks by land classes. The work for NMFA by FAO is directly applicable in these actions. These types of inventory systems would need large resources in data collection, and are challenging even for countries with advanced inventories (e.g., Cienciala et al. 2008).

Our concerns related to the requirements of REDD are those discussed in the previous section under change detection, i.e., how to get the estimates precise enough and even how to detect some changes at all with a sparse design. The methods and data sources discussed under change detection section are relevant for the purposes of REDD.

In addition to the efforts to reduce the emissions from deforestation, efforts and tools to promote afforestation are needed. The national assessment should thus include also information on climatic and soil characteristics, in addition to socioeconomic aspects. This information could be further strengthened in NFMA.

But perhaps the biggest advantage of FAO NFMA program, compared to other potential national forest carbon inventory approaches, is its ability to assess the socioeconomic and institutional aspects of human forest uses associated with the forest measurements. As such, it may be the only existing and functioning program that has the capabilities to monitor the sustainability of REDD program participation. Such monitoring capabilities are crucial if the REDD is ever going to work for the benefit of the rural poor in developing countries (Peskett, et al., 2008). We have the impression that this represents an underexploited advantage, which has not been emphasized enough in the program's promotion of the NFMA approach to REDD monitoring.

C.1.4 Identification of possible data sources

As given above, and as was seen in the sampling error analysis, further data could be needed to enhance the applicability of the estimates and their reliability. The field data are often the most expensive component in a forest inventory or land monitoring and assessment system. All efforts to utilize also the other data sources, in addition to field data should be taken.

A modern inventory design should take into account the existing relevant data sources. The applied data for the forest inventory can be a) field data, b) air-borne remote sensing data, c) space-borne remote sensing data, and d) other existing covering data, e.g., digital maps or information from possible earlier inventories, e.g., management inventories. Although the information is not necessarily valid for the analysis, it could be applicable in planning the sampling design.

It is clear that *field data* composes the basic data source for any seriously done large area forest inventory.

Currently, there are many possibilities for *air-bore remote sensing* material, e.g., digital air-photos, and lidar data. In the context of large area inventory, air-borne remote sensing data could be employed to replace part of the field data (at least in areas difficult to access) and to get additional and complementary field data type data about some core variables but not from all variables. Aerial photographs and lidar data could be an efficient data combination. Air-borne remote sensing data can be used as a part of two-phase sampling.

Space-borne remote sensing data can be applied in at least four different non-exclusive ways:
a) to calculate forest resource estimates for smaller areas than what is possible using sparse field data only; examples are areas like some tens or some hundreds of thousands of hectares instead of some millions of hectares b) to produce covering wall-to-wall maps about forest resources, c) as stratification basis for stratified estimation, and d) for detecting some changes like disturbances (McRoberts et al. 2002, Reese et al. 2002 and 2003, Tomppo 2006b, Tomppo et al. 2008a, Tomppo et al. 2008b).

A very high resolution space-borne remote sensing data could be the fifth data source but is yet hard to integrate as a part of a large area operative inventory due to the high costs and problems in data availability. The use of this type of data could be considered in the future using image samples. However, high resolution and very high resolution remote sensing data could be relevant when using with a sampling approach, especially in land use change monitoring and in fulfilling the requirements of REDD (Section C.1.3). The importance of field data, including soil data, should be kept in mind when planning methods for REDD purposes.

C.3 Planning of the inventory by design units

The planning of a sampling design for a forest inventory is a demanding task. It needs for input data some information about forests and their structure as well as information about land use distribution. I an ideal case, a complete model of forests and land use of the target country, or its sub-regions should be available. Furthermore, some cost assessment should be available as well as the requirements for the core parameter estimates. A complete model of forests is very seldom available, even for countries with advanced inventories. If some kind of relevant forest and land use data are available for inventory planning, the methods given in Tomppo et al. (2001) and in Appendix 4 (Tomppo and Katila 2008) can be applied. In these methods, the costs to measure a plot or a cluster of plots, are taken into account.

A basic principle in sampling design is that each observation and measurement should bring as much new information as possible. This is normally fulfilled if the observation points are 'far enough' from each other. Figures 1 and 2, examples from Finland, illustrate the situation. The distance of 2 km between the observations would yield about zero correlation and maximal amount of new information. On the other hand, if the observations are far from each other, the traveling (walking) time from one observation point to the other is high and increases the measurement costs. The optimum is a trade-off between the new information of an observation and traveling costs. Note that similar semivariograms and correlations can be calculated from the existing NFMA data with the distances present within one tract. The correlations of the observations between tracts are very likely zero. The calculated characteristics would give information about the applicable distances between observations. A preliminary inventory in a few small sub-regions in a country of interest would also give some information about spatial variation of land use and forest characteristics.

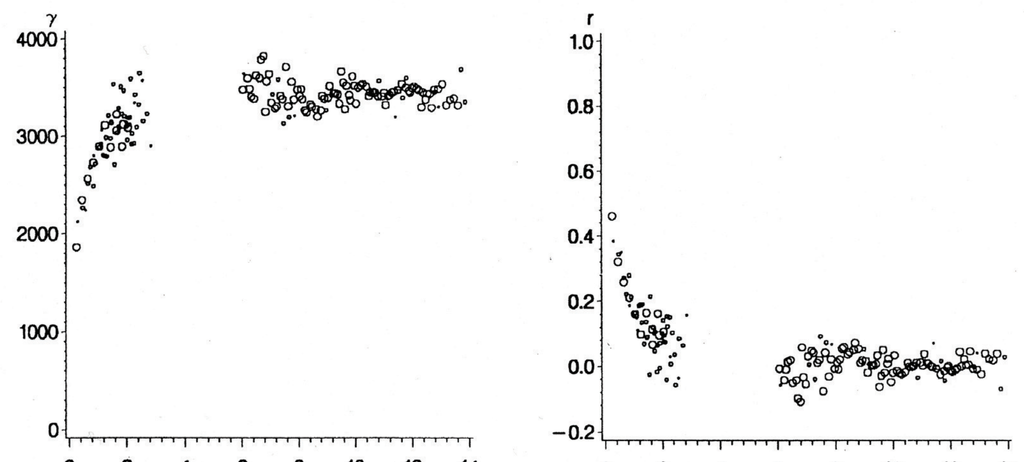


Figure 1. The estimated semivariogram and correlation of the volume of growing stock on forest land in Central and North Central Finland in NFI7 (1977-84) (from Tomppo, Henttonen and Tuomainen, 2001).

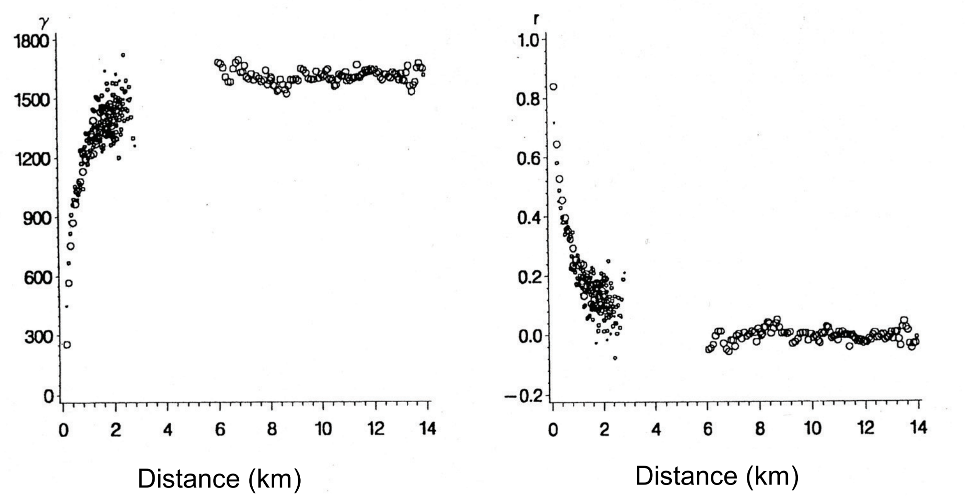


Figure 2. The estimated semivariogram and correlation of the age of stands on forest land in Central and North Central Finland in NFI7 (1977-84) (from Tomppo, Henttonen and Tuomainen, 2001).

Other important aspects to be considered when planning an inventory are:

1. Attention should be paid to the size of the measurement unit like a tract or a cluster of the field plots. Particularly, when the traveling or walking distance to the site is long, as often in Tropics, if is efficient to measure several field plots on one site. This requirement is already fulfilled in NFMA. On the other hand, maximizing the new information from each plot, the distances between the plots should be high enough. Particularly, in the case of a good or moderate access to the site, it is beneficial to usually arrange the field plots into clusters. A cluster could be the work of one day for a field crew. It is expensive and inefficient to travel to the same place (tract, cluster) several times. This rule should be modified to Tropics due to the fact that in tropical countries, the situation is more complicated due the difficult accessibility of the tracts and plots. "Sample site locations are often far from roads or rivers. Up to 30 km walk if not more is sometimes needed. Field crews need to walk for days to tract location and from tract to another with camping inside the forest. Field surveys are subject to different circumstances, most are characterized by uneasy access and distant locations" (Saket et al. 2008). One solution in these cases could be to arrange to the plots into small clusters around the "main site" in such a way that each cluster would be a work of one day.

2. Land use observations within a plot cluster and between sub-clusters would be cheap and could be integrated into the calculation system in a statistically sound way. An example is the lengths of land classes between the plots. This should not be very time consuming with the modern GPS systems.

2. The size and shape of field plots should be decided and adapted to small scale variation of forests, or within stand variability of forests when relevant. A further aspect when planning the size and shape of a plot is the use of ground data with space-borne remote sensing data. In large area inventories, an efficient plot is usually rather small due to the fact that within stand variation of forests is small (nearby trees are on the average more similar than trees far apart from each other). The requirements of remote sensing and statistical efficiency requirements may be contradicting when using remote sensing data of medium pixel size like Landsat 5. One should also note that the use of remote sensing of data is not necessarily technically too complicated when taking into capacity building plans, and that the coordination of capacity building and training could suit to FAO.

The small scale variation of forests in Tropics deviates from that in Boreal and temperate regions and a fairly large size a plot, like NFMA plot, could be argued. In any case, the plot size and shape could be considered for each country separately. The size and shape could be selected from a set of some basic alternatives. In the planning work, some information about the small scale variability of forests is needed. The forest data of a similar region or a vegetation zone could be one model for the forests. In addition to the current plot size and shape of NFMA, the basic alternatives are a set of concentric plots; the radius depends on the breast height diameter of a tree, and an angle count plot (Bitterlich plot). The radii also depend on the variable in question, e.g., a shorter radius for dead wood than for living trees.

3. Further stratification on the basis of accessibility could increase the efficiency of an inventory. The stratification and the estimation can be done in such a way that the requirements of a sound statistical basis are fulfilled. The basic sample can be made sparser, e.g., on the basis of needed time (or total costs) to reach a field plot cluster. The sampling probabilities are applied in the final estimation.

4. As given above, some remote field plots / field plot clusters can be 'measured' on the basis of air-borne remote sensing. The measurement error should be added to the total errors. In theory, the measurement errors should be added also for field measurements, but, the measurement errors are significantly smaller when using field measurement than when using air-borne data.

One problem in planning the sampling design and plot layout is often the lack the available data. In some countries, management data could be available for some regions. One possible data source could the land cover maps based on remote sensing analysis. Although they include errors, they could be employed in sampling design planning in a robust way. If some covering digital data are available, the planning of sampling designs can be done as follows. 1. Potential basic alternatives are identified, that is, sampling density, the number of the field plots per cluster, the cluster shape, the distances of the plots in a cluster, the distances between clusters (see, e.g., Tomppo 2006a, and Swedish NFI publications). 2. A large amount of samples are selected using the same design but different 'starting point' (Tomppo et al. 2001, Tomppo and Katila 2008, Appendix 4). It is sufficient to select some representative tests areas for sampling simulation from the design units, or alternatively do the simulation with the country level data. 3. The standard deviation of an estimate computed from different samples can be considered as a sampling error. On the basis of the Finnish experiences, this method works very well in practice and has been employed since early 1990s using the output maps of the multi-source NFI. The errors based on sampling simulations are near the real errors, for error estimation, see, e.g., Heikkinen (2006). This approach has been employed in simulating the standard errors and also the traveling costs in Appendix 4 (Tomppo and Katila 2008).

C.4 Socioeconomic and Institutional Data

In each tract, field crews collect information about forest users and their use of the resource. These data are collected through a variety of methods, including secondary data sources (i.e. census data), direct observations (i.e. harvesting activities, cattle grazing, etc), but principally through different types of interviews with local resource users themselves. Because of the methodological challenges involved in collecting high quality of data from interviews, we focus our technical review on these. The sampling design for the selection of interviewees in each tract is particularly critical for the quality of data.

The NFMA manual describes three different methods for data collection through direct interactions with local people: interviews with key informants (i.e. local individuals with a reputation of being knowledgeable about forest use), focus group discussions (i.e. meeting with of local resource users to discuss resource use patterns), and household surveys (i.e. households that are located within a certain distance from the center of the tract). Seven out of the eight countries that have completed their assessments rely mostly on information provided by key informants and to some extent on focus group discussions. For both these forms of interviews, NFMA field personnel select interviewees through a purposive sampling design. This involves seeking out individuals whom local people consider to be particularly knowledgeable about local forest use. Field crews typically rely on qualitative information provided by local leaders and elders to identify these individuals.

In the cases of Zambia and Kenya, however, NFMA collaborators have added a third form of interviews: formal household surveys with 16 randomly selected households within a certain distance from the center of each tract. The NFMA field manual provides excellent step-by-step instructions for how field personnel should handle the random selection of these households.

There are several benefits of going beyond interviews with key informants and focus groups and carrying out household surveys. First, it improves the precision of the socioeconomic parameter estimates by augmenting the number of observations (that may be combined to estimate each parameter). These additional data points also help to provide more reliable interpretations of the data provided by key informants and focus group discussions (through cross-checking and triangulation). Finally, drawing data from a suite of different but complementary forms of interviews increases the confidence in the validity of data. This is particularly important when trying to measure processes with such high degree of complexity as is the case for forest user patterns in non-industrialized societies.

Ultimately, the quality of the data collected through these different interviews will depend on the degree to which these procedures for sampling and interviewing that are presented in the field manual are actually followed. When it comes to the field application, we note several opportunities for continuing to improve the sampling design for the interview components of the NFMA program.

We identify four main areas in which the program may improve its performance with regards to data collection through interviews: (1) Weak links between biophysical measurements and data gathered though interviews (2) The limitations of relying on key informants and focus groups alone; (3) Systems for quality control; and (4) The use of existing data sources in sampling design.

Weak links between biophysical and interview data

One of the fundamental justifications for collecting data through interviews is that this information is useful for producing policy-relevant knowledge at both the national and international levels. The idea is that the data on forest users and their relationship to forests will help policy makers identify priority areas for policy interventions at the national level. For example, the data may indicate that 30% of the country's rural residents do not have secure access rights to fuel wood. The data may also show a significant correlation between the insecurity of access rights and the degree of forest degradation. This type of analysis would be extremely valuable for policy analysts and decision makers.

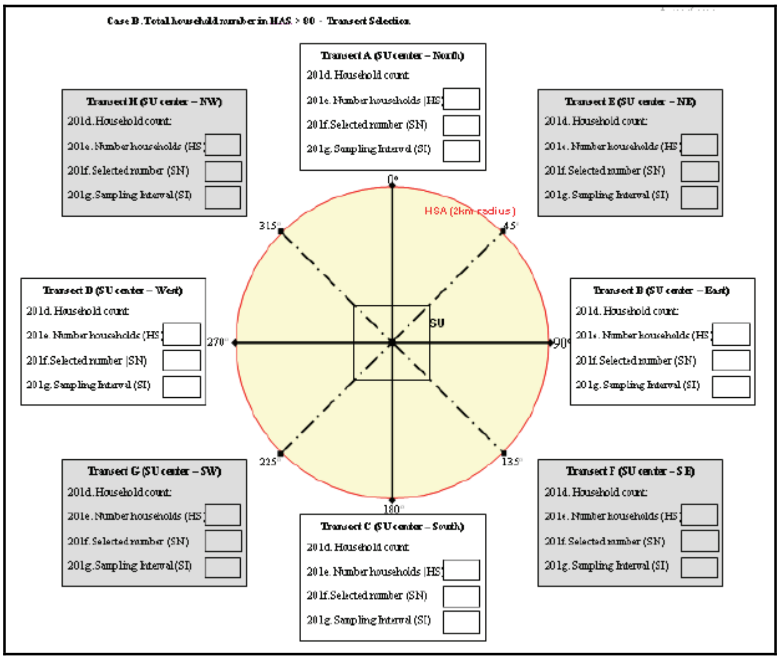
The problem is that the current NFMA sampling design for interviews limits the validity of such analytical results because it is difficult to determine the spatial location of the forest use described by users in interviews. The boundaries of the tract are perceived as artificial constructs by the interviewee and it is difficult to limit answers about forest use to this abstract domain. The tenuous links between the biophysical and socioeconomic data is further weakened by utilizing sampling units for the two types of data that are of different spatial extents. In Zambia, the difference in the spatial extent of the sampling unit for socioeconomic data and direct biophysical measures was about 77.5 km^2. The implication is that analysts using the NFMA data cannot be very sure that the forest use data corresponds to the biophysical data, and this limits their analytical power.

We propose that the program introduces an additional interview protocol for the focus group discussions that collects data on ten critical variables related to forest use within the tract boundaries. By systematically applying this protocol in all field sites, analysts can be more confident that the socioeconomic data corresponds more closely to biophysical measurements. We present this protocol in Appendix 1 at the end of the report.

We also suggest that the program explores more potential measurement synergies between the biophysical and socioeconomic data collection procedures. For example, it might be a good idea to have the individuals who responsible for conducting household interviews to also record GPS points for changing land cover on the landscape. As per the instructions in the NFMA Field Manual for the selection of households, field crews are supposed to walk from the center of the tract in direction of 360˚, 270˚, 180˚, and 90˚, towards the edge of the x km-radius circle. If, after these four hikes, the crew still has not identified 16 households, they will carry out four more hikes from the center in the direction of 315˚, 225˚, 135˚, and 45˚. The figure below illustrates these instructions graphically.

In the case of Zambia, these instructions imply that household interview field crews walked as much as 40 km just to identify who the potential household interviewees were without generating any other data points. This seems like a missed opportunity to capture other data. We propose that the program explores ways in which the crews might combine these log hikes with simple biophysical measurements, such as observations about land cover/ land use changes on the landscape.

Figure 3. Graphic illustration for determining household sample



The limitations of relying on key informants and focus groups alone

When the sole sources for socioeconomic data are key informant interviews and focus groups it is more difficult for team leaders to hold data collectors accountable for acquiring valid and reliable measurements. There is much less documentation required to support each data entry. And while the NFMA manual is very elaborate and clear in its instructions about how good data collection through interviews should be carried out (and we find that the manual provides very good guidance on this) it is often difficult to assess that field staff actually cross-check data and triangulate sources as instructed. .

Conducting surveys with randomly selected households is therefore a welcome addition to the suite of methods used for data collection through interviews in the NFMA. This complementary method adds great value to the NFMA programs. This is demonstrated by the ILUA experiences in Zambia and Kenya.

We are convinced that the benefits of conducting household surveys as part of the social data collection far outweigh the costs. The gains are mostly associated with improved *reliability* of data collection methods (multi-source approach), improved *validity* of all social data collected in the site (more independent data to cross-check and triangulate measures that are particularly difficult to measure) as well as increased *precision* in estimating socioeconomic parameters (more observations). Let us take an example to illustrate this point.

For the sake of illustration, we will compare the overall precision achieved for interview variables in the cases of Cameroon and Zambia. In Cameroon, interview data was collected through interviews with key informants while in Zambia, the ILUA combined three data sources: household interviews, key informants and focus groups. To carry out the comparison, we calculate sampling errors for the proportion estimates with the most conservative assumptions with regards to interview responses. We assume that each interview variable rendered a 50-percent proportion. The formula for calculating the standard error under this assumption is as follows:

$$\text{Standard error} = \sqrt{\frac{\rho(1-\rho)}{n}} = \sqrt{\frac{.50 \times .50}{n}} = \sqrt{\frac{.25}{n}} = s.e.$$

Hence to find the standard error for interview data in the two countries, we only need to know the number of interviews carried out (assuming normal distribution). As shown in Table 3 below, such calculations render significant differences in the precision of estimates derived from interview data in Zambia and in Cameroon.

Table 3: Comparison of sampling errors for NFMAs with and without household surveys

Country	*Tracts*	*Interviewees*[1]	*Standard error (for 50% -proportions at 95% confidence level)*
Cameroon	236	500	4.38
Zambia	227	1910	2.40

This comparison, which is for illustrative purposes only, shows that the precision of estimates from interview data may improve by as much as 47 percent as a result of introducing household surveys.

Another reason for why believe it would be worthwhile to consider making household surveys a regular component of the NFMA method is that it provides more structure to the collection of socioeconomic data. Guidelines for how to select households, how to conduct interviews, and how to report results are clearer and more detailed than for qualitative interviews. Because of the increased clarity and the requirement for staff to document each of the steps involved in carrying out the surveys, it is possible for team leaders to hold these staff accountable.

Observed limitations of the Household Interviews

[1] This calculation assumes that 2-3 individuals were interviewed in Cameroon, but it is not clear from the national report how many individuals were actually interviewed. It also makes the much more conservative assumption that in Zambia a total of 1910 individuals were interviewed (1683 documented household surveys plus 1 key informant per tract).

The NFMA approach to household interviews does, however, face several constraints. Some of the perceived limitations of the household interviews include (a) difficulties in communicating the true meaning of questions to interviewees; (b) the large number of questions in each interview, and (c) difficulties in assessing the represenattaiveness of the observations. What follows is a short discussion on how these limitations might be addressed.

(a) Difficulties in communicating the true meaning of questions

If a question is perceived as complex, and interviewees have trouble understanding its meaning, we recommend that the question is dropped from the interview protocol because the question will render highly unreliable responses. One way of addressing problematic questions is to invest more in field testing before the NFMA is carried out. During this phase, interviewers document which are the most difficult questions. After identifying these, the team of interviewers can discuss ways of simplifying or otherwise modifying the wordings. This same exercise should be carried out at the end of each NFMA and ILUA so that future NFMAs in other countries may benefit from the lessons learned in previous countries' interview experiences. It would be particularly important to capture the more experienced field crews' expert knowledge of how one might rephrase questions to improve on clarity.

(b) Large number of questions.

The large number of questions means that household interviews may take considerable time to complete. Interview crews in Zambia reported that in some cases one household interview tool as long as 1.5 - 2 hours to complete. A large share of interview questions concern products and services. Interviewees ask for a complete inventory of all products and services used by each household. These questions are identical to questions asked to key informants and focus groups. One way of reducing the time spent in each household would be focus questions on the three most important products and services rather than asking question about the full set.

While there may be an excess of detail when it comes to certain sets of questions, it is surprising to note the complete absence of other potentially very important questions. For example, in the available data from household surveys from Zambia, we were unable to identify data collected on variables such as the level of schooling in each household; personal health indicators; degree of direct dependence on forest resources for the household's economy; access to public services—such as health services, primary education, and forestry extension services or other forestry-related personnel from external organizations, as well as estimates of the total number of households in each tract. The analysis using household data from Zambia, presented in Appendix 2, was complicated by the absence of such variables because existing analytical work on forestry policy refer to these variables as potentially influential.

(c) Difficulties in assessing the representativeness of the observations

The NFMA team has expressed some concern over the difficulties in assessing the representativeness of household interview data at the tract and provincial levels. Much of this problem is related to the fact that the total number of households is not a piece of data that is collected in each tract. This is a critical variable to collect data on because when populations are small, the size of the sample becomes critical for estimating representativeness.

Systems for quality control

No matter how detailed the instructions in the field manual and no matter how competent the field staff is, there are no guarantees that all data will be collected according to the established protocol. While it is important to monitor field crews and periodically check the quality of their work, it is often more effective to create quality control systems that reward good performance rather than punishing staff for the opposite.

Such a reward system may involve offering incentive payments to field teams that provide exceptionally well-documented support for the coded data collected through interviews. Such documentation may be in the form of photographs with interviewed individuals and groups, materials from Participatory Rural Appraisal exercises, and maps that mark observations made during transect walks with user group representatives. Simply asking questions to interviewers about why they have coded information in a certain way is often sufficient for team leaders to get a sense of the level of rigor that the they applied to collect and interpret the data.

Ultimately, much of the quality of the data depends on the relationship between team leaders and the individuals responsible for data collection. No system of control, punishment, or rewards can compensate for a breakdown in this crucial relationship.

The use of existing data sources in sampling design

Just as the precision of NFMA field measurements may be improved by relying on existing land cover data for the sampling design, so can the efficiency of data collection through interviews be improved by building on existing or planned efforts of data collection in the country in question.

For example, in some countries it may be possible to join forces with organizations that have carried out (or plan to) national household surveys, i.e. population census, agricultural census or World Bank-supported Poverty and Vulnerability Assessments (PVA). In the case of the ILUA program in Zambia, a PVA was carried out in 2005, which coincided partially with the data collection for the ILUA in Zambia, but the two programs collected their household data independently and with different designs.

In some cases, it may be of mutual benefit to seek compatibility between survey systems of other organizations or to agree on a future design that is acceptable to both NFMA and partner organizations. The gains of seeking out such synergies are not limited to the increased precision of estimates but it also makes it possible to link the NFMA data to issues that are normally beyond the scope the typical NFMA program.

D. Statistical Framework

This section reviews the statistical framework of the NFMA programs. We focus our review on how the national components make use of statistical inference to learn about the state of their country's forest resources and how these are being used by local people. For this, we examined the national reports of Bangladesh, Cameroon, Guatemala, Honduras, Lebanon, Philippines, and Zambia.

D.1 Biophysical calculations

In result calculations, basic estimators of ratio estimation and stratified ratio estimation have been employed with equal inclusion probabilities for the expected values and variances. The independence of the observations has been assumed. The given formulas are correct and very likely correctly used.

In error estimation, the observation of one tract (i.e., from the plots in a tract) has been merged into one observation. This is also our recommendation due to the closeness of the plots. Underestimates of the error estimates will be obtained if the variables on the observation units are spatially correlated and are assumed to be independent in the estimators. There are some studies showing that spatial correlation of mean volume of growing stock or the number of the species is quite low even at low distances in Tropical rain forests (e.g. Singh 1974). The spatial correlation of land classes often deviates from that of volume and tree species distributions. Keeping in mind that the inventories should also produce the estimates of land class areas, the spatial correlation of different variables needs further and country specific investigations.

Our first comment related to NFMA results calculation is that fact that, in practice, the inclusion probabilities vary in latitude longitude sampling with increasing inclusion probabilities towards North and South from the Equator. This leads overweighting of the observations measured at locations further away from the equator relative to observations measured closer to the equator. The seriousness this problem depends on how far the target country is from the equator. We encourage checking one more time the analysis in this respect. The problem could be overcome by attaching varying inclusion probability (area representativeness or plot expansion factor) into each plot and tract, and therefore does not constitute a major problem. The area represented by each plot could be derived, e.g., from the areas of the four nearest rectangles restricted by the latitudes and longitudes, or using the areas of Voronoi cells as the weights of the plot clusters. Voronoi cells are made up of polygons which are created around geographical entities, such as spatially distributed object points, e.g., trees or plot centers, and a closeness principle. Each polygon contains those points of the space which are closer to that specific object point than any other point (Voronoi 1908).

Our second comment concerns the use of the possible other existing data or remote sensing data. The efficiency could be increased with minor costs when using either post-stratification or small area estimation.

Forest inventory and statistical textbooks involve large amount information about statistical inference relevant for statistical analysis. The principles given in the books give good basis for statistical guidelines. In addition to what the books give, we would like to emphasize the following points:

Three types of estimates can be seen from the entire NFI system:

1. Large area estimates and error estimates based on field data only. This group includes also the change estimates. Note that a part of 'field data' could come from air-borne remote sensing. The estimates should be computed by strata. The stratum-wise estimates and error estimates can be considered independent which makes it trivial to merge stratum-wise estimates to nation level estimates. Post-stratified estimation within the basic strata can be done if suitable data are available, e.g., the old management data or new maps based on multi-source inventory (field data and space-borne remote sensing). This method would increase the efficiency of the field data with small additional costs (McRoberts et al 2002, Nilsson et al. 2007).

2. Multi-source estimates, i.e. statistics for small areas, can be calculated using field data, space-borne remote sensing data and other available data (Reese et al, 2003, Tomppo, 1992, Tomppo and Halme, 2004, Tomppo 2006b, Tomppo et al. 2008a and 2008b).

3. Map form predictions of core forest variables based on all available data, i.e., field data supported by air-borne remote sensing data, space-borne remote sensing and other digital data. Map form estimates can be derived also from field data only.

Furthermore, we would like to emphasis on the following points.

4. It is important to have error estimates for all parameters.

5. The result calculation principles, possibly with the calculation formulas should always be given in the reports. This is important not only for the users but for the wider audience to increase the trust.

D.2 Socioeconomic data analysis

For the analysis of socioeconomic data we pay particular attention to the national teams' treatment of uncertainty and the extent to which the reports discuss the implications of limited accuracy and precision of the interview data.

Analysis of Uncertainty

One of the fundamental rules in the analysis of interview or survey data is the explicit calculation and discussion of the level of uncertainty generated by data collection and estimation processes. There are two major sources of uncertainty that should be addressed in any analysis of informant based on interviews: namely sampling error and measurement error. All the NFMA country reports that we reviewed for this report presented results from interview data, in both tables and diagrams, but none of them sampling and measurement errors into account. This can be very misleading to readers. .

By including estimations of different types of error—based on the number of interviewees, the way they were selected, their respective interests in relation to forest use, and the informants' social and economic positions—a more robust interpretation of the interview data is be possible.

Sampling error

For forest mensuration data collected, it is relatively straightforward to calculate valid estimates of variance, standard deviations, and thereby confidence intervals for these continuous variables. For interview data, however, some unique problems arise when estimating sampling error. The problems are due to the nature of the variables measured, which are either binary (values are either 0 or 1), ordinal (values represent order of importance or rank, or nominal (categories without any particular ordering properties). Such categorical variables contain less variance, because measurements are fit into predetermined categories. And due to the non-continuous nature of such variables, special statistical techniques need to be employed when calculating sampling error for categorical data.

Simply put, sampling error is the difference between the sample estimate and the corresponding population's true parameter value. Using conventional (parametric) statistical techniques to calculate the sampling error for any given measure requires that the sample is normally distributed (bell-shaped distribution curve). But when you have data that consists mostly of 0 and 1, it is not self-evident what a normal distribution looks like. In this, researchers often make assumptions about the distribution based on how the sample was drawn. Random and systematic sample designs are known to generate normal distributions for all types of data.

Since FAO's NFMA follows a systematic sample strategy one might be tempted to conclude that interview data is always normally distributed. This is not always true, because the degree of normality will ultimately depend on how interviewees were selected in each tract. In the cases in which randomly selected households are interviewed in each systematically selected tract (such as the case of Zambia and Kenya), the normality assumption will hold. But for interview data using more qualitative selection procedures (interviewing key informants and focus groups) the data may or may not meet the normality criterion. To maintain normality in these cases, it is important to follow an identical procedure for identifying interviewees in each site. Such procedures are described in the FAO NFMA Manual as well as in the FAO-IUFRO Knowledge Reference.

Assuming normality, it is possible to calculate the precision of particular measures and estimates of the interview data. Consider the following example: For a 95-percent confidence interval and for questions where the sampled interviewees' answers were split down the middle (50 % answering "yes" and the other 50% answering "no", which is the most conservative estimate for calculating interview sampling error) the sampling error for a sample of 260 interviews produces an estimated sampling error of 6.8%. For questions where a smaller or larger proportion responded affirmatively the sampling error will be even smaller. Illustration 1 below offers an example of how sampling error may be calculated for categorical variables from NFMA interview data. Reporting on such errors in relation to particular estimates in the results should be standard procedure for all NFMA reports.

It is considered good practice to account for the degree of precision when presenting any analytical results derived from a sample. All NFMA reports should therefore make it a habit to present sampling errors for all quantitative variables reported, regardless of whether these measure socio-economic or biophysical phenomena. But sampling error is only one component of the total measure of uncertainty in a given result. There are other types of errors that are important sources of uncertainty in the NFMA. Measurement error is of particular concern for the NFMA interview component and the next section discusses how this type of error may be accounted in the reporting.

Illustration: Calculating Sampling Error for Binary Interview Variables

Because a proportion is the same thing as the mean of a two-value distribution (if yes=1 and no=0, then the mean and the proportion of yes-sayers is the same thing) it is possible to calculate the standard errors of the proportions by estimating the variance of the proportion: $\rho * (1-\rho)$ (assuming a normally distributed sample). The standard error of that proportion will depend on the value of that proportion itself but for a conservative calculation let us assume it to be exactly 50%. Let us also assume that we interviewed a total of 260 individuals: Standard error

$$= \sqrt{\frac{\rho(1-\rho)}{n}} = \sqrt{\frac{.50 * .50}{260}} = 0.034.$$

The correct interpretation of this result is that at the 67% confidence level, the true proportion will be in the range from 46.6% to 53.4% ($\pm$ 1 standard error). At the 95% confidence level, the true proportion of the population lies within a band of two standard errors from the estimated mean, in this case $\pm 6.8\%$. At the 99% level, the confidence interval is three standard errors wide, in this case just over $\pm$ 10%.Note that the same formula for proportions may be used to estimate the precision of estimates for categorical variables that have more than two possible values. In these cases the proportions would reflect the distributions of the various categories for each variable.

Measurement error

All research designs relying on interviews need to take into consideration the potential influence of *measurement error* on the reported results. This type of error refers to participants' limitations related to "memory, understanding, and willingness to respond truthfully to questions, and as a consequence distort the quality of results" (Niemi, 1993). Measurement errors in the NFMA interviews refer to difficulties to obtain valid and truthful information about people's relationships to trees and forest resources. Consider the following example: If local users do not enjoy undisputed and officially recognized property rights they are likely to be reluctant to reveal the full array of products and services that they derive from these resources. But even if users are perfectly legitimate and legal users of the resources, they may also be reluctant to provide accurate information to strangers. After all, even legal users don't have anything to gain—only lose—from revealing information about their use. It is therefore a good idea to expect that forest use reported by users themselves is systematically underestimated. This would be an example of a biased result. Bias occurs when measurement repeatedly tends toward one direction or another or, in the worst case, the direction is unknown.

When the direction of the bias is known it is possible to make a post-facto correction—albeit qualitative—for the bias in the reported results. It is more problematic when the direction of the bias is unknown. Such a bias could occur if the variability in forest use is very high but the interviewees do not reflect this variability. For example, relying on a particular local actor—such as a local government employee or a farmer association leader—as the *only* key informant for the interviews in all sites will produce a one-sided view of forest use although such use may in reality be multi-faceted and complex. Under such an approach, a skewed and inaccurate view of the actual forest use will emerge.

Non-responses in surveys represent another type of measurement problem that is very difficult to deal with. This may be the most difficult source of measurement error to deal with since it is hard to learn much about those individuals who did not participate in interviews (Fowler, 1993). In the NFMA interviews, field crews are under a great deal of pressure to finish their fieldwork on time. If one of the pre-selected interviewees is not available or refuses to be interviewed, field personnel will select an alternate interviewee without necessarily recording that the person who was pre-selected could not participate. Consequently, the NFMA interview sample is likely to be systematically biased towards those individuals who have more time to talk, and who have less to lose from divulging information about their forest use. We strongly advise the NFMA to incorporate non-responses in the field protocols so that NFMA teams may estimate its influence on total uncertainty of sample estimates.

Another potential source of inaccuracy is the respondent's hidden agenda with regards to local forest use. Interviewees may deliberately conceal or distort information even if they do not have an apparent reason to do so. Without proper triangulation and cross checking of responses such inaccuracies are virtually impossible to detect. Utilizing a multi-source approach, which includes a suite of methods for data collection on socioeconomic data will contribute to more accurate data because with more sources of different types you increase your ability to assess the validity of interview responses.

All these measurement problems affect the accuracy of the sample estimates. The crux of it is that unlike sampling error, it is not possible to calculate the precise size of the measurement error. That does not mean that it should not be addressed in the reports. What it does mean is that reports need to discuss the influence measurement error in more qualitative terms by addressing a series of key issues. Some of these issues include how interviewees were selected, how many individual interviews were carried out, if and how interviewers were trained, if and how interview instruments were pre-tested and validated, among others.

The FAO-IUFRO Knowledge Reference for National Forest Assessments describes a basic approach for how interviewees should be identified. According to the FAO-IUFRO-recommended approach, measurement error may be partly mitigated by selecting interviewees according to their interests in the tree-related products and services. By interviewing the widest variety of local actors possible—with respect to their different interests in products and services—the sample estimates will be less biased. Since it is not possible to calculate this bias in any mathematically exact way, the NFMA teams should describe the detailed measures taken to address measurement error. Doing so will enhance the transparency of the research, as well as adding to the credibility of the results presented. The illustration below outlines a series of steps that the NFMA teams are advised to follow when analyzing and presenting the NFMA interview results. This is information that the readers need for proper interpretation of the results.

Illustration: Addressing Measurement Error for Interview Variables

<u>Diagnostic questions for assessing measurement error in interviews:</u>

1. How was the interview instrument developed?
2. How many field tests were carried out?
3. What was the result of the field test?
4. Who carried out the interviews?
5. What training did the interviewers go through?
6. How were interviewees identified and selected?
7. How many interviewees were interviewed in total?
8. Did the number of interviewees vary form one tract to another? Why?

E: CONCLUSIONS AND RECOMMENDATIONS

As external reviewers we find that FAO's support to NFMA has been extremely important in meeting member countries' and partner organizations' demands for more and better data about forests and their users. We believe this program has done more for the improvement of the quality of globally available forest data that any other program that we have been in contact with.

At the same time, because of its innovative orientation, ambitious scope, and relatively short history, we believe it is of utmost importance to reflect on how things may be done even better. Only with a keen sensitivity for how to adapt to the changing conditions and shifting demands will a program like this one be able to maintain its steadfast leadership. Adaptation requires learning and experimenting with ways of doing things even better. Our recommendations should be viewed as our input into this continuous learning process.

1. **Explore alternative sampling designs and plot lay-outs.** Our related sampling simulation study in Appendix 4 shows that the NFMA design is not as efficient for estimating biophysical parameters as the tested alternative designs. One of our most important recommendations is that the program should seriously reconsider promoting a blue-print sampling design because what is cost-effective data collection in one country will not be the same in all countries. Needs for accuracy, scope, and emphasis are different from country to country. The availability of existing data varies from country to country, and as we have shown, the cost-effectiveness of any sampling design depends is largely determined by how effective the design is in employing the existing data.

   We find that the current plot layout is time consuming and similar trees are measured again and again. Our preliminary analysis suggests that one would be able to generate more or less the same level of precision for estimates of biomass volumes even if one measured one third as many trees as is currently done in the NFMA.

2. **Promote experimentation and pilot studies to learn how the NFMA design may be made even better.** Encouraging countries to experiment with alternative

designs and then comparing results with other experiences will enrich all NFMA participants. Pilot studies on new ways of doing things may lead to more efficient designs for responding to specific needs of different member countries. One area in which the program should invest in such experimentation is for national forest carbon accounting related to participation in UNFCCC REDD initiative. Another urgent topic for a pilot study would be "appropriate design and methods for estimating over-time changes in forest parameters" utilizing data from NFMAs that have been carried out more than once (which will hopefully occur very soon).

3. **Continue promoting the collection of socioeconomic and institutional data through interviews as part of the NFMA approach.** It is not only a defining characteristic of this program, but it also provides much needed data on potential causes for observed variation in forest measurements. Hence it helps policy makers to understand the reasons for why forest conditions vary across space and time. But perhaps more importantly, it is data from this component that will allow us to test the effectiveness of policy and varying governance arrangements at local and national levels to induce sustainable use of forests. All of these wonderful potential benefits, for a relatively meager marginal cost.

4. **Strengthen the links between biophysical field measurements and data gathered though interviews.** We propose that the program introduces an additional interview protocol for the focus group discussions that collects data on ten critical variables related to forest use within the tract boundaries. By systematically applying this protocol in all field sites, analysts can be more confident that the socioeconomic data corresponds more closely to biophysical measurements (see appendix 1).

   We also suggest that the program explores more potential measurement synergies between the biophysical and socioeconomic data collection procedures. For example, it might be a good idea to have the individuals who responsible for conducting household interviews to also record GPS points for changing land cover on the landscape, as they walk from one household to the next. The interview crews cover great distances by foot when identifying the household sampling units and could potentially combine these hikes with simple biophysical measurements.

5. **Establish surveys with randomly selected households as the core of a "multi-source" approach to socioeconomic and institutional data collection.** We are convinced that the benefits of conducting household surveys as part of the social data collection far outweigh the costs. The gains are mostly associated with improved *reliability* of data collection methods (multi-source approach), improved *validity* of all social data collected in the site (more independent data to cross-check and triangulate measures that are particularly difficult to measure) as well as increased *precision* in estimating socioeconomic parameters (more observations).

6. **Invest in quality control systems that reward good interview performance** No matter how detailed the instructions in the field manual and no matter how competent the field staff is, there are no guarantees that all data will be collected

according to the established protocol. Some countries seem to have been more rigorous than others in introducing systems for quality control. We recommend that the lead agency in each country follows the example of Guatemala, Honduras and Nicaragua; and conducts routine controls with in-situ re-measurements to ensure compliance by the field crews. While it is important to monitor field crews and periodically check the quality of their work, it is often more effective to create quality control systems that reward good performance rather than punishing staff for the opposite.

7. **Exploit opportunities to use existing data sources in sampling design.** There are opportunities to make better systematic use of remote sensing data on land cover and land use to improve cost-effectiveness of design and statistical framework. It is important to note, however that such incorporations should not come at the cost of fieldwork, but should be seen as a complement to field measurements. It is an emerging consensus in the forest inventory science community that by combining remote sensing and field measurements one is in a position to learn as much as ten times as much as compared to relying exclusively on one source or the other (provide examples from experiences in US, Sweden, Finland). All countries applying NFMAs would benefit from integration of RS data in the sampling design stage of the NFMA. We recommend that the RS and field analyses be carried out in an integrated fashion by one and the same agency. The RS component should not be outsourced because this would jeopardize some of the synergy effects.

   Similar opportunities exist to make the sampling design for the interview component more efficient. The efficiency of data collection through interviews may be improved by building on existing or planned efforts of data collection in the country in question. For example, in some countries it may be possible to join forces with organizations that have carried out (or plan to) national household surveys, i.e. population census, agricultural census or World Bank-supported Poverty and Vulnerability Assessments (PVA).

8. **Invest more in analysis.** Although this review has focused on the methodological considerations involved in the organization of data collection, we cannot end this review without urging that more emphasis to be given to the need for more and better analysis of all NFMA data. There is an incredible wealth of data available, but so far very little of it has been utilized in scientific studies. We propose that system is created that makes some version of the data-sets (without coordinates) accessible to interested and respectable members of the research community. We are convinced that having more scientists using this data would not only deliver more knowledge to the interested parties, but it would also augment the program's visibility. Ideally, the analysis should be carried out by the in-country colleagues together with other analysts. Supporting training opportunities for NFMA colleagues to continue to develop their analytical skills seems like a crucial part of such an endeavor.

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APPENDIX 1: PROPOSED DATA COLLECTION PROTOCOL FOR STRENGTHENING LINK BETWEEN BIOPHYSICAL MEASUREMENTS AND FOREST USE DATA

The purpose of this protocol is to increase the confidence that some specific forest use variables that are measured through interviews with forest users correspond to the biophysical measurements at the tract level. To accomplish this, we propose that a special questionnaire is developed. This questionnaire should not be administered individually to forest users or households, but rather used as a coding device to record the results of focus group discussions.

Before the gathering the focus group for discussion, invite a couple of the tract's key informants to accompany the interview team to walk around the tract (~4km). Start the focus group discussion by asking the members who just walked with the team, to describe for the rest of the participants where they just walked. Ask them to draw the route on a wall-paper so that all participants can see. It is important all participants share an understanding of where the boundaries of the tract are and which forest resources exist inside as well as outside these boundaries. Explain to participants that all questions that they will be asked to discuss pertain to the resources **inside** the boundaries that were just described.

The following ten questions should be asked as questions for discussion—not as questions for which there is necessarily only one correct answer. It is important to try to get as many participants to weigh in on the answers as possible.

1. Which three products do you consider to be most important for most households that use forest resources within this particular area?

2. Approximately how many households benefit directly from each of these products? (households that are harvesting these products from this area/benefiting from services directly)?

3. What proportion of these households reside inside the boundaries of the tract? 1-5km from the tract center?, and >5km from the tract center?

4. Are there any rules that constrain these households' uses of products?

5. If so what is the origin of these rules? (mark all that apply)

    a. Private owner dictates the conditions for access and use

    b. Local community norms and customs (no formal rules)

    c. Local community rules/bylaws (formal rules, often written down)

    d. Local Government ordinances

    e. Central government rules and regs

    f. Open-access (law of the jungle)

g. Other

6. Who are the legal owners of the land within the tract?

    a. private individuals _____%

    b. community holdings _____%

    c. national government _____%

    d. Private corporations ____%

    e. Other ____%

7. Have there been any efforts to manage or somehow organize the forest resource use within this area?

8. If so, who led this effort?

    a. NGO

    b. local community

    c. private owner

    d. Local Government

    e. National Government

    f. corporation

    g. other

9. Is the effort ongoing?

10. Is/was the effort successful?

    a. very unsuccessful

    b. not very successful

    c. somewhat successful

    d. very successful

APPENDIX 2: EXAMPLES OF STATISTICAL ANALYSIS USING DATA COLLECTED THROUGH INTERVIEWS

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INTRODUCTION

One way of increasing the usefulness of the NFMA data analysis for policy makers would be to analyze relationships between variables that are of particular policy concern. In the NFMA Knowledge Reference, Persson and Janz (2004) identify seven areas of concern for policy makers: Forest use; the present state of forests; change; plantations; trees outside forests; the role of forests for local communities, and other issues such as ownership and environmental benefits.[2] For instance, a national government involved in creating policies that are supportive of sustainable forest management, will be interested in learning about such things as the prevalence of conflicts in relation to specific products and varying external conditions, the level of awareness about forestry legislation among forest users, as well as the relationship between land tenure and forest health just to mention a few. Creative use of the NFMA interview component in combination with the other components of the program can help provide such analytical results. The next section describes how a careful analysis of the socioeconomic and institutional data can help to shed light on several policy-relevant issues related to the human use of forests.

EXPLORING RELATIONSHIPS BETWEEN SOCIOECONOMIC, INSTITUTIONAL, AND FOREST VARIABLES

The purpose of this section is to illustrate the types of simple relational analyses using interview data that the NFMA teams may draw on for their country reports. As a point of departure, we construct six hypotheses on themes that policy makers involved in forestry are likely to be interested in. Many of these hypotheses have their origin in the literature on the role of public policy in supporting sustainable forestry (i.e. Gibson et al., 2000; Ostrom, 1999; Thomson, 1992; Arnold, 1998; White and Martin, 2002; Repetto and Gillis, 1988).

There are several functions of governmental authorities that can support the achievement of sustainable forest management. Ostrom (1999) suggests that governmental organizations may have a particularly important role to play in backing up local efforts to monitor and enforce property rights, providing forest users with forums for conflict resolution as well as developing and disseminating information about the condition of the resource beyond the local domains. This larger scale information is often crucial as a first step towards more effective policy interventions. With these critical public policy functions in mind, we have developed a series of hypotheses that stipulate specific relationships between selected NFMA variables—

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2 (See section 4.3 Types of information normally needed; What information is needed? http://www.fao.org/forestry/foris/webview/NFMA-ref/index.jsp?siteId=2621&sitetreeId=7287&langId=1&geoId=0)

interview variables in particular. The purpose of the section is to illustrate how hypothesis-testing using NFMA interview data may generate useful knowledge for actors interested in supporting sustainable forest management. A secondary purpose is to demonstrate how different types of analysis may be applied to data generated from key-informant interviews as well as household interviews. For the latter, we use ILUA household data from Zambia.

The six hypotheses to be tested in this appendix are presented according to policy area in Table 1 below.

Table 1: Main Hypotheses

Policy Area	***Hypotheses***	***Data Used***
Forest User Conflicts	H1: Conflicts related to the use of forest products and services are more likely to occur when users perceive a shortage of these products/services.	Key Informant Interviews from NFA **Philippines**
	H2: Conflicts over scarce forest products/services are more likely when such products are related to the food security of users—such as firewood for cooking, fruits for household consumption—than for products and services related to other areas such as commercial extraction or recreation.	Key Informant Interviews from NFA **Philippines**
	H3: The likelihood that conflicts occur is higher when harvesters share the rights to those products than when there are property rights that are exclusive to the harvesting individual(s).	Key Informant Interviews from NFA **Philippines**
Policy Interventions	H4: Areas from which products and services are harvested by users who comply with forestry legislation, are in better condition than areas in which users do not.	Key Informant Interviews from NFA **Lebanon**
	H5: Households that harvest products primarily for commercial purposes are more likely to be aware of forestry legislation and incentive programs than those who harvest the same products for primarily domestic purposes	ILUA **Zambia** Household Data
	H6: The Richer and more educated households are, the more likely they are to apply for support from forestry incentives programs	ILUA **Zambia** Household Data

These hypotheses make use of many of the interview variables included in the NFA. We did not select any particular variables because we thought they were more or less relevant for a particular country. In the actual NFA reports, however, it would be wise for each country to be selective of the particular relationships that are the most relevant for policy actors in each country. The purpose of this section is to *illustrate* the type of relational analysis that is possible to carry out with existing NFA interview data. The purpose of this section is *not* to provide substantive conclusions about the results or policy implications for any particular country's NFA. The latter requires more intimate knowledge about the policy process in each country—something the NFA teams are best suited to do.

Some of these hypotheses have already been tested in FAO NFMA working paper #4 (Andersson and Svendsen, 2006). There are two main differences between the previous analysis and the one performed here. First, Andersson and Svendsen (2006) employed binary correlation techniques (so-called cross tab analysis) to test for associations between binary interview variables of interest. Here, we will test hypotheses using multivariate regression techniques, which have the advantage of allowing for testing the influence of a particular variable *while simultaneously holding constant other potentially important determinants.* Second, while Andersson and Svendsen (2006) relied exclusively on binary data from key informant interviews, here we also make use of household data from the 1,236 sampled households interviewed in the Zambian ILUA.

HYPOTHESES ABOUT USER CONFLICTS OVER FOREST RESOURCES

Starting with the importance of conflict resolution forums, it would be of interest to policy makers to be able to identify the conditions that are associated with a high likelihood of forest-related conflicts occurring in their countries. The first three hypotheses analyze this topic.

H 1: Conflicts related to the use of forest products and services are more likely to occur when users perceive a shortage of these products/services.

The logic behind this hypothesis is that when products are perceived as scarce people value them more and therefore are prepared to dispute the control over these resources (Homer-Dixon, 1999). If a local group enjoys recognized property rights to their products, such scarcity-related conflicts may actually serve as catalysts for mobilizing the community to self-organization for greater monitoring and enforcement of such property rights (Gibson, 1999). On the other hand, if products are abundant, users are less likely to put up a fight to gain control over the products, and conflicts are therefore less likely to materialize.

H2: Conflicts over scarce forest products/services are more likely when such products are related to the food security of users—such as firewood for cooking, fruits for household consumption.

The hypothesis introduces the idea that forest-related conflicts are motivated not only by scarcity but rather by a combination of scarcity and **salience** of the product. Products related to the food security of the users are likely to be viewed as the most salient products by the users themselves. If a product was simply scarce but not very important to the users, we would expect that conflicts would not arise as frequently as when both conditions are met. We test this idea by analyzing how the relationship between scarcity and user conflicts change depending on the type of product considered. We test this tri-variate relationship by creating an interaction term and include this in the regression.

We define **salience as** the degree to which any product is related to food security. If a product is directly related to food security we assign a value of 1, and if not the variable takes on a value of 0. Food security-related products were defined as: firewood, medicinal plants, fodder, and food items. We then separate the entire sample (n=4306) according to whether the product is salient or not and end up with one dataset of 2264 observations (less salient) and another with 2042 observations (salient).

H3: The likelihood that conflicts occur is higher when harvesters share the rights to those products than when there are property rights that are exclusive to the harvesting individual(s).

Results H1-H3

We use the NFA data from the Philippines to test whether the hypothesized relationships hold in this context. The outcome variable for the first three hypotheses is a binary variable that denotes whether forest users experience any conflict associated with their use of any of these products and services. The descriptive statistics for all variables used to test the first three hypotheses related to conflicts are reported in Table 2 below.

Table 2: Descriptive statistics for the dependent and all independent variables

Variables	Obs (n)	Mean	Std. Dev.	Min	Max
User Conflict	3992	0.192	0.394	0	1
Population on Site	4140	333.5	884.4	0	9515
Dis. Health Centre	3835	14.10	18.13	0	252
Des. – Production	3954	0.900	0.301	0	1
Private Tenure	4152	0.515	0.500	0	1
State tenure	4152	0.479	0.500	0	1
Not Excl. Rights	4056	0.416	0.493	0	1
Perc. Shortage	3235	0.309	0.462	0	1
Salience	4123	0.417	0.493	0	1
Interaction: Shortage X Salience	3233	0.113	0.317	0	1

Because of the binary nature of the outcome variable, we use binary logit regression techniques in our hypothesis testing. We regress the user conflict variable on all the independent variables, which other analysts have found to be important determinants of natural resource conflicts (for details, see Andersson and Svendsen, 2006). Table 3 reports the results of the regression analysis. Because some of the variables are measured at the product/service level while others are aggregate measures at the tract or LUCS levels, we robust and clustered errors for all regressions (for more on the logic of these measures, see Long, 1997)

Table 3: Binary Logit Results

Dependent Variable: User Conflict	Odds ratio	Z-statistic
Population on Site	1.000	(-0.53)
Distance from Health Centre	0.994	(2.05)*
Designation – Production	0.623	(2.95)**
Land Tenure - Private	1.424	(-0.40)
Land Tenure - State	4.258	(-1.62)
Exclusive Rights	0.052	(9.12)**
Perceived Shortage	1.637	(3.67)**
Salience	1.548	(3.04)**
Interaction: Shortage x Salience	0.673	(-1.87)

Observations: 2760 products and services
* significant at 5% significance level
** significant at 1% significance level

The results presented in Table 3 allow us to test the first three hypotheses for the Philippines. The regression results support the validity of the first hypothesis that there is a link between shortage of forest products and the occurrence of forest user conflicts. According to the results in Table 3, when there is a perceived shortage of forest products, user conflicts are 1.64 times more likely to occur. The result is significant at the 1-percent significance level.

As far as the second hypothesis goes—that conflicts over scarce forest products/services are more likely when such products are salient to users—the regression results fail to reject this relationship
In fact, in the regression model, we can see that when products are related to food security (fuel wood / human food), user conflict is 1.5 times more likely to occur ($p<0.01$). The interaction variable did not turn out to be significant, which would suggest that the effect of shortage perceptions on conflict does not depend on the salience of the product, at least not in an additive, linear fashion.

For policy makers interested in facilitating the prevention or peaceful resolution of resource user conflicts this finding would suggest that such prevention efforts may fare better if they target areas where products from forests and TOF are both scarce and salient to the population at large. How to design such a policy intervention, however, can be very challenging. One of the confounding factors that is likely to complicate any policy intervention is the current allocation of property rights. The third hypothesis introduces property rights into the analysis of the preponderance of conflicts.

We also fail to reject the third hypothesis—that products that are perceived as relatively scarce are associated with a higher likelihood of conflicts when harvesters share the rights to those products. The regression results show that when harvesters have exclusive rights, the odd ratio is .052, which means they are $1/20^{th}$ less likely to have user conflict compared to when harvesters do not have exclusive rights. The regression coefficient for this variable is statistically significant at the 1-percent significance level.

It is interesting to note that if harvesters have no legally recognized rights to the product or service, the odds ratio is 3.91, meaning they are almost 4 times more likely to have user conflict (not reported in table 3 due to the nature of dummy variables -- not all three variables can be in the model at the same time).

One caveat in this analysis, however, is that "rights" are not necessarily formal property rights issued by the government but actually represents the interviewees' de facto perception of mutually recognized property rights. As such the finding does not say much about the effectiveness of formal property rights in regulating access to resources or their ability to prevent natural resource-related conflicts. Hence, subsequent studies would need to appreciate more fully the relationship between formal property rights, de facto rights and the occurrence of conflicts. It is also worth noting that the exclusive rights are not necessarily individual ownership rights but can also be private group property as is the case of corporations or communities, which constitute groups of individuals who hold a private property rights to a resource.

HYPOTHESES ON POLICY INTERVENTIONS

Perhaps of most interest to policy actors are the types of analysis that examine the effects of policy interventions on different governance outcomes, including forest conditions. Here, we offer several examples of such analysis. We start by using key-informant interview data from NFA Lebanon to test the following hypothesis:

H4: Areas from which products and services are harvested by users who comply with forestry legislation, are in better condition than areas in which users do not.

The outcome variable "forest condition" that we use is a continuous variable that measures the proportion of trees in each tract that are healthy. We are particularly interested in testing the effect of forest users' awareness of government legislation associated with products and services harvested in the tract on this outcome variable. However, there are many other variables that are also likely to influence this outcome, which means that we need include as many of these other variables in the analysis as possible. Table 4 lists the descriptive statistics for the dependent variable as well as all independent variables.

Table 4: Descriptive Statistics for the dependent and all independent variables

Variable	Obs	Mean	Std. Dev	Min	Max
Tree Quality	2110	0.954	0.118	0	1
Population on Site	2106	390.9	891.3	0	7000
Dis. Health Centre	2074	6.078	4.029	0	25
Des. – Production	2108	0.972	0.164	0	1
Private tenure	2079	0.877	0.329	0	1
Leg. Awareness	2110	0.225	0.418	0	1
Leg. Compliance	2110	0.127	0.334	0	1

Results H4
To test the proposed relationship between legal compliance and proportional tree health in each tract, we regress the tree health variable on (1) the total population in the tract; (2) Distance from Health Centre (denotes degree of infrastructure development and resource dependence); (3) whether the forest is designated mostly for forestry production purposes; (4) whether the land tenure is private (5) whether users of a particular product are aware of any legislation associated with that use; (6) and whether users comply with existing legislation associated with their use of the product. The results from the ordinary least square regression are presented in Table 5 below.

Table 5: Ordinary Least Square Regression Results with robust and clustered standard errors.

Dependent Variable: Tree Quality (Lebanon)	Coeff	Student t
Population on Site	-0.000	(-1.50)
Distance from Health Centre	-0.005	(7.21)**
Designation - Production	-0.081	(4.23)**
Land Tenure - Private	0.041	(2.14)*
Legislation Awareness	0.04	(6.48)**
Legislation Compliance	-0.005	(-0.65)
Constant	1.009	(46.92)**
Observations	2021	
R-squared	0.05	
Robust t statistics in parentheses		
* significant at 5%; ** significant at 1%		

The regression results support the validity of the hypothesis—that areas from which products and services are harvested by users who comply with forestry legislation, are in better condition than areas in which users do not. Legislation awareness is significantly associated with increased tree quality. In quantitative terms, users who are aware of legislation use forests that have four percent more healthy trees than the forests used by people who are not aware of such legislation. This positive effect is statistically significant at the 1% significant level, while holding other potentially influential determinants constant.

It is also interesting to note that Private land tenure appear to have a similar effect on tree health ($p<0.05$), while infrastructure development (as measured by distance from the tract to the nearest health center) has a statistically significant negative effect ($p<0.01$) as does production forest ($p<0.01$).

The next three hypotheses all use Zambia's ILUA household survey data. Descriptive statistics of all dependent independent variables used in the testing of the next three hypotheses are presented in Table 6 below.

Table 6: Descriptive Statistics for Zambia Household Data used in Hypotheses 5-7

Variable	Description	Minimum	Maximum	Mean	Std. Dev.
Treequality	Proportion of trees in a tract that are in healthy/ only slightly affected condition	0	1	0.89	0.15
Treequalitydummy	Dummy variable (0=less than mean, 1=more than mean)	0	1	0.56	0.50
Forestincawareness	Awareness of forestry incentives for the product/service by legal users	0	1	0.29	0.45
Forestincapplication	Application to forestry incentive for the product/service by legal users	0	1	0.08	0.28
Income	Total annual household income in 1,000s of ZKW (1 < 100; 2 = 100-500; 3 = 500-1,000; 4 = 1,000-5,000; 5 > 5,000	1	5	2.74	1.18
Percentliterate	Proportion of household that is literate	0	1	0.46	0.29
Co-management	Proportion of tract with formal management plan formulated and implemented between owner and communities/private companies allocated for extraction purposes through licenses or timber concession	0	1	0.13	0.32
Forestdummy	More than 50% of tract is dominated by forest land use class	0	1	0.72	0.45
Propcommercial	Proportion where commercial (mainly sold in the local, national or international markets) is the main end-use of product/service	0	1	0.02	0.10
Propopenaccess	Proportion of product/services for a household where the use of a product/service is available to all without restrictions	0	1	0.40	0.48
Distanceextension	Distance to extension services in kilometers (proxy for access to government services)	0	500	34.47	51.23

H5: Households that harvest products primarily for commercial purposes are more likely to be aware of forestry incentive programs than those who harvest the same products for primarily domestic purposes.

The rationale for this hypothesis is that knowledge about the existence of government provided economic incentives is likely to be greater among those actors who harvest products for commercial purposes. It would sense that people who seek to profit economically from harvesting seek out opportunities to improve the economic performance of their harvesting activities. Participating in incentive programs might be a way to do so, depending on the design of the program.

H6: The richer and more educated that households are, the more likely they are to apply for support from forestry incentives programs.

One of the great frustrations of many well-designed pro-poor forestry policies is the difficulty in reaching the forest users who would most benefit from such policies—in this case the rural poor. It is often difficult and costly to disseminate the information about the existence of the policy to these groups. As a result these groups often lack awareness about the opportunities that they are missing. We test whether this is actually the case among the sampled households in Zambia.

Results H5-H6

Because the outcome variables in the last three hypotheses are all binary variables, we use binary logit regression to test the hypothesized relationships. The results are presented in Table 7 below.

Table 7: Logit Regression Results

	Model 1:Incentive Awareness		Model 2: Incentive Application	
Variables	**Odds Ratio**	**z**	**Odds Ratio**	**z**
Literacy (%)	1.506	(-1.80)	1.364	(-0.80)
Income category	1.160	(2.64)**	1.186	(1.82)'
Co-management	3.179	(5.73)**	2.959	(3.98)**
Distance to ext. service	0.997	(-1.42)	1.002	(-1.03)
Open access rights (%)	1.139	(-0.96)	0.326	(-4.16)**
Forest dummy	1.130	(-0.83)	0.653	(-1.89)'
Commercial end use (%)	1.330	(-0.49)	2.902	(-1.44)
n	1246		1246	
Pseudo r2	0.035		0.068	

‘ = Significant at the 10-percent level
* = Significant at the 5-percent level
** = Significant at the 1-percent level

For the fifth hypothesis—that those households that harvest products for commercial purposes are more likely to be aware of forestry incentive programs—does not receive any empirical support from the regression results. The odds ratio for commercial end use is not statistically significant at the 5-percent level of significance. What does seem to have an effect on the likelihood of a forest user being aware of forestry incentives is the individual user’s income level. The higher the income level, the more likely that the forest user is aware of incentive programs associated with the products that they harvest. The possibility exists that this effect is an artifact of the specific products that the country's incentive programs target, and these products may not be harvested by the poorest households. Another variable that has a significant and positive effect on the likelihood of incentive awareness is the existence of co-management activities, in which multiple actors have agreed to share management responsibilities to a forest that is held in common. This variable has the strongest effect of all independent variables in the first model.

The regression results lend weak support to sixth hypothesis and the notion that richer and more educated household members are more likely to apply to forestry incentives programs. The odds ratios for the literacy and income variables are both greater then 1, meaning that the effect is positive, but none of them are statistically significant at the 5-percent level. The income variable is significant at the 10-percent level. Two other independent variables seem to have the strongest effects on the likelihood of a household applying for forestry incentives. Again co-management has a strong positive effect while the proportion of forest lands whose access is not regulated and may therefore be considered open-access has a strong negative effect. Households that harvest products primarily from open access forest lands are almost 60 percent less likely to apply for forestry incentive programs than users who harvest primarily from forests that are not open access in nature.

CONCLUSION

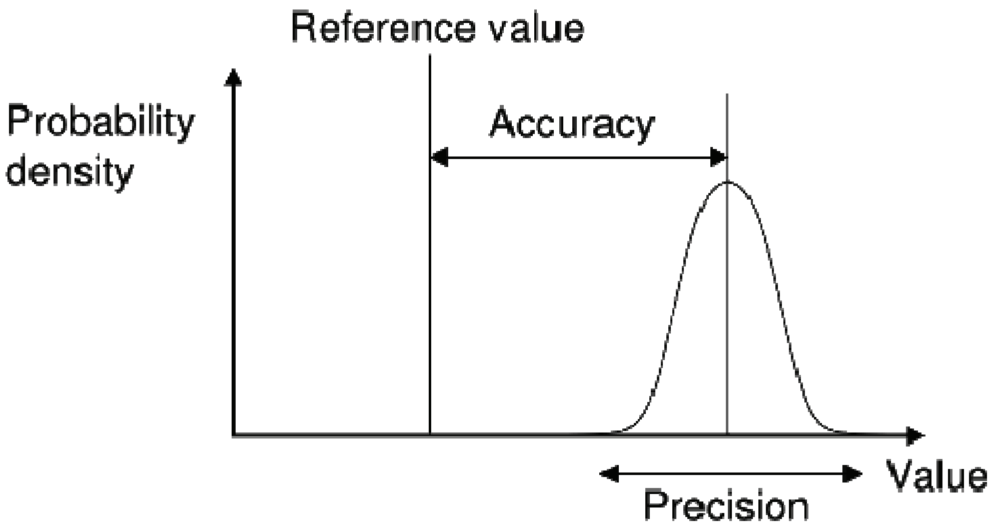
In this brief appendix, we have tried to illustrate how the statistical analysis of interview data may be used to learn about several relationships between variables that are relevant for public policy in a variety of different contexts. We tested the strength and direction of the relationships spelled out in the six hypotheses presented at the beginning of the appendix. We found that using data from interviews enabled us to uncover several statistically significant relationships between socioeconomic, institutional and biophysical variables. We believe this is a good testament to the additional explanatory power that interview data bring to the NFMA.

As NFMAs repeat data collection over time, the degree to which NFMA users will be able to identify the factors that explain longitudinal changes in forests will depend to a great extent on the availability of reliable and valid socioeconomic and institutional data collected through interviews.

APPENDIX 3: GLOSSARY

Accuracy
Accuracy is the degree of conformity of a calculated quantity to its actual (true) value.

Precision
The degree to which random errors affect a set of measurements; high precision means that the overall random error is small. A random error is one which, when averaged, approaches zero as the number of observations increases.



Reliability
Reliability means that by applying the same *measurement procedure* in the same way you will always get the same result (King et al, 1993: p. 25). In other words, Reliability is concerned with the degree to which measurements are repeatable and consistent (Nunnally, 1965). The following analogy may be helpful to understand the concept: "If a well-anchored rifle is fired but the shots are widely scattered about a target, the rifle is unreliable" (Zeller and Carmines, 1980: 48).

Validity
Validity means that measurements correspond closely to the true value of the measured object. Using the rifle analogy again: "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)" (Zeller and Carmines, 1980: p. 77). The illustration shows how it is possible to have a set of indicators that are perfectly reliable, but because they are plagued by a systematic error or bias, the indicators do not represent the concept that we want to measure.

Reporting unit *is* an administrative or ecological region for which the NFI estimates are calculated and reported. The entire area of a country can be divided into non-overlapping reporting units. The union of the units comprises the entire area of the country. Note that this means stratified sampling.

Design unit is a region in which the same NFI method is applied, including field data and field plot density as well as remote sensing data. The union of the design units is the entire area of the country.

APPENDIX 4: COMPARING ALTERNATIVE SAMPLING DESIGNS FOR NATIONAL AND REGIONAL FOREST MONITORING

Comparing alternative sampling designs for National and regional forest monitoring

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Abstract

We present a method to compare the efficiencies of the sampling designs of forest inventories by means of the standard errors of the selected parameters and field measurement costs. The method is applied to the designs of United Nations FAO National Forest Monitoring and Assessment (NFMA)), the proposed 'Eurogrid' designs of European Union, as well as systematic or stratified cluster-wise sampling design. Thematic maps of the Finnish multi-source forest inventory are employed as models of forests in the simulation study. The measuring costs of different designs are assessed using information from Finnish national forest inventory and earlier time studies. The walking distances are assessed using GIS -based analysis on the maps of multi-source inventory. A similar technique without GIS -based cost analysis has been applied in designing Finnish National forest inventory in an operative way since early 1990's.

The study shows that the FAO NFMA design, consisting of tracts of four field plots and Eurogrid consisting of detach observation points, is inefficient when comparing to cluster-wise design with sampling density adapted to variability of forests.

The presented method can be employed with any georeferenced data, including information of the variables of interest and having a spatial resolution of about the size of the sampling unit and ,e.g., with remote sensing based land land cover or land use predictions or forest management data.

KEYWORDS: forest inventory, sampling simulation, standard error, GIS

1 Introduction

The Food and Agriculture Organization of the United Nations (FAO) has collected global level forest information since 1947. UN-ECE/FAO (United Nations Economic Commission for Europe/FAO) has co-operated with FAO in collecting and publishing the Temperate and Boreal region data (UN-ECE/FAO, 2000). The latest report, FRA 2005 was published in late 2005. Forest resources assessment is mainly based on NFI systems at national and regional levels. These schemes were set up to fulfill national needs and international commitments, such as the Forest Resource Assessment (FRA) conducted by FAO every 10th year, or currently every 5th year. Although countries report to these global resources assessments, the base definitions in the countries are not harmonized. The process of converting national NFI data to international UN/FAO requests is done individually by each country without any mechanism to control the comparability and the harmonization of these reports. That is, in spite of global definitions, there are no specific harmonization tools and processes to fulfill EU needs such as market oriented production or environmental EU requirements (MCPFE indicators for example).

Countries are planning and conducting the inventories on the basis of their own information needs and traditions. Some countries have long traditions, from the beginning of 1920s, while other countries have conducted just one inventory or are even planning the first sampling based inventory, or at a global level, are lacking even the first inventory. While some inventories are wood production oriented, some other inventories are targeted to produce information about non-wood goods and services, or are multi-purpose inventories. Most inventories collect information on the same base variables; however, some inventories collect some hundreds of parameters measured on the field. Most of the current NFIs are sampling-based inventories. Countries that were conducting stand level inventories are moving slowly to sampling-based inventories, using in many cases, remotely sensed data as ancillary information.

FAO has carried out excellent work in assisting countries in establishing their forest inventories. In addition to the common definitions and support work, e.g., through regional meetings and training schools, targeted to Forest resource Assessment (FRA) program, a comprehensive inventory method called National Forest Monitoring and Assessment (NFMA) has been established (FAO, 2008). Currently, NFA has been completed in seven countries (Bangladesh, Cameroon, Costa Rica, Guatemala, Honduras, Lebanon and Phillipines), is in progress in ten countries (Angola, Republic of Congo, Kenya, Kyrgyzstan, Zambia, Brazil, Algeria, Nicaragua, Uruguay and Comoros) and Formulated for eight countries (Cuba, Nigeria, Vietnam, Tanzania, Ecuador, Uzbekistan, The Gambia and Macedonia, FAO 2008).

European administrations and policy makers need comprehensive data on forest resources at the European level. Information on forest resources has traditionally been used for forest policy decision making by Member States, taken at the national and sub-national levels. Practically all of the Member States collect forest data through national forest inventories (NFIs). NFIs provide information relevant for national level decision making, policy formulation and monitoring for forestry and relevant sectors, as well as for forestry planning in smaller geographical or political units at the sub-national level. During the past decades, the scope of forestry has become wider and the information needs have increased. The monitoring of forest resources for assessing the vitality of trees and forests, forest biodiversity and the role of forests in global carbon cycle have become important issues. NFIs already provide information on some or all of these topics.

In addition to forest inventories at the national level, other monitoring efforts were established in Europe by the European Commission. In particular, two regulations on the monitoring of the effect of atmospheric pollution and forest fires were established in 1987 and 1992, respectively. hese were the Reg. 3528/86 on the Monitoring of Atmospheric Pollution in Forests and Reg. 2158/92 on Forest Fire Prevention. This latter regulation was complemented by Reg. 804/94 for the establishment of an information system for forest fires, the so-called Common Core Forest Fires Database.

A topical question in Europe is should European forest information supply be established on harmonized and strengthened NFIS or should some kind of European level forest inventory system be established. An advantage of NFIs is that the sampling designs and information content have been adapted to national and local variability of forests and information needs. A drawback is the lack of harmonization.

European Union COST Action E43 was launched to harmonize definitions and concepts of European NFIs in such a way that NFIs could provide comparable data (www.metla.fi/eu/cost/e43/). On the other hand, a unified Eurogrid has been proposed. The grid would consist of detached points, with distances, e.g., of 16 km $\times$ 16 km or 4 km $\times$ 4 km.

Let us first recall some basic concepts of in sampling theory.

1. Target population is a set of the elements for which the inference is to be made. Population can be discrete (finite or infinite) or continuous (always infinite, e.g. a real plane, a forest area).

2. A sample s is a subset of the population.

3. Sampling frame is the mechanism which allows to identify the elements in the population.

4. The set of all samples is denoted by *S*.

5. Selection probability of a sample is denoted by *p(s)*. The sampling frame usually determines the selection probability of each sample.

6. Inclusion probability of an element,

$$\pi_i = \sum_{s:U_i \in s} p(s) \qquad 1$$

tells the probability that an individual U_i is included in an arbitrary sample. Note that the inclusion probabilities can vary and that the most efficient sampling procedures often rest upon unequal probabilities (e.g., Mandallaz 2008, see also Gregoire and Valentine 2008).

One basic principle in probability sampling is that each element in the population must have a positive inclusion probability. The inference concerns that set of the elements which have a positive inclusion probability. Note that each sample *s* does not have to have a positive inclusion probability. It is important to take into account the unequal probabilities in the inference. Otherwise, biased estimates may result.

In this study, the efficiencies of NFMA design and the proposed Eurogrid design (denoted by EUROGRID) of detached plots of 4 km $\times$ 4 km grid are compared to cluster-wise designs. The two basic plot densities are 1) the density corresponding the NFMA design one tract at the crossing of every latitude and longitude, and 2) the plot density with a plot grid 4 km x 4 km. The samples are picked up from the output thematic maps of the Finnish multi-source National Forest Inventory. A similar method has been used in NFI designing since early 1990s (Tomppo et al. 2001, Katila and Tomppo 2006). The costs are based on costs studies in planning the design of the Finnish NFI (Päivinen and Yli-Kojola 1983, Henttonen 1991). Furthermore, walking time in forests is assessed using data base of Land Survey Finland and GIS analysis. The purpose is not to present an optimal design with some given costs, but rather to demonstrate a method that could be applied in sampling studies at global and European level, and particularly that cluster-wise sampling design, possibly with some stratification, is more efficient than a design consisting of nearby large plots or detached plots.

2 Study area and material

The study is conducted throughout Finland, the land area being 30.447 million hectares and forestry land area 26.277 million hectares. The output maps from the operative multi-source NFI are applied (Figure 1). The maps have been created using field sample plots of the 9th NFI, in total about 70 000 plots on forestry land in the country, satellite images, digital map data and non-parametric k-NN estimation (e.g., Tomppo 1996, Katila and Tomppo, 2001, Tomppo and Halme, 2004, Tomppo et al. 2006, Tomppo et al. 2008a). The total volume of growing stock on the basis of the NFI9 (1996-2003) is 2091 million m^3, the volume of Scots pine (*Pinus sylvestris* L.), 999.7 million m^3 Norway spruce (*Picea abies* (L.) Karst.), 694.7 million m^3, birch (*Betula* spp.), 325.2 million m^3 and other tree species, mainly aspen (*Populus tremula* L.) and alder (*Alnus* spp.) 71.7 million m^3. The volume of saw timber is 626.9 million m^3.

The applied output thematic maps of multi-source NFI employed in this study are mean volume of growing stock of all tree species (denoted by ALL) (m^3/ha), mean volume of broad-leaved tree species other than birch (m^3/ha) (denoted by OBL) and the volume of saw timber (m^3/ha) (denoted by SAW). All volumes concern forestry land (FRYL). Note that forestry land is the union of forest land, poorly productive forest land and unproductive forest land (Tomppo 2006a).

The volume of OBL represents a rare object in sampling inventory and the volume of saw timber stands for the trees with a DBH of at least 20 cm, employed in NFMA. All themes include information about land use classes (Figure 1), making it possible to estimate the error of forestry land area estimate.

3 Methods

3.1 Sampling simulation and designs

FAO NFMA design consists of tracts with four plots (FAO 2004). In the basic design, the plots are located at the intersection of every latitude/longitude (FAO 2004). The trees with a DBH at least of 10 cm and less than 20 cm are measured from the subplot 1 (SPL1) and the trees with a DBH at least 20 cm the whole plot. Only the total number of trees by species is measured for tree with a DBH less than 10 cm (SPL2).

We study the sampling errors of the following parameters:
a) area of forestry land (ha),
b) mean tree stem volume of growing stock (m^3/ha),

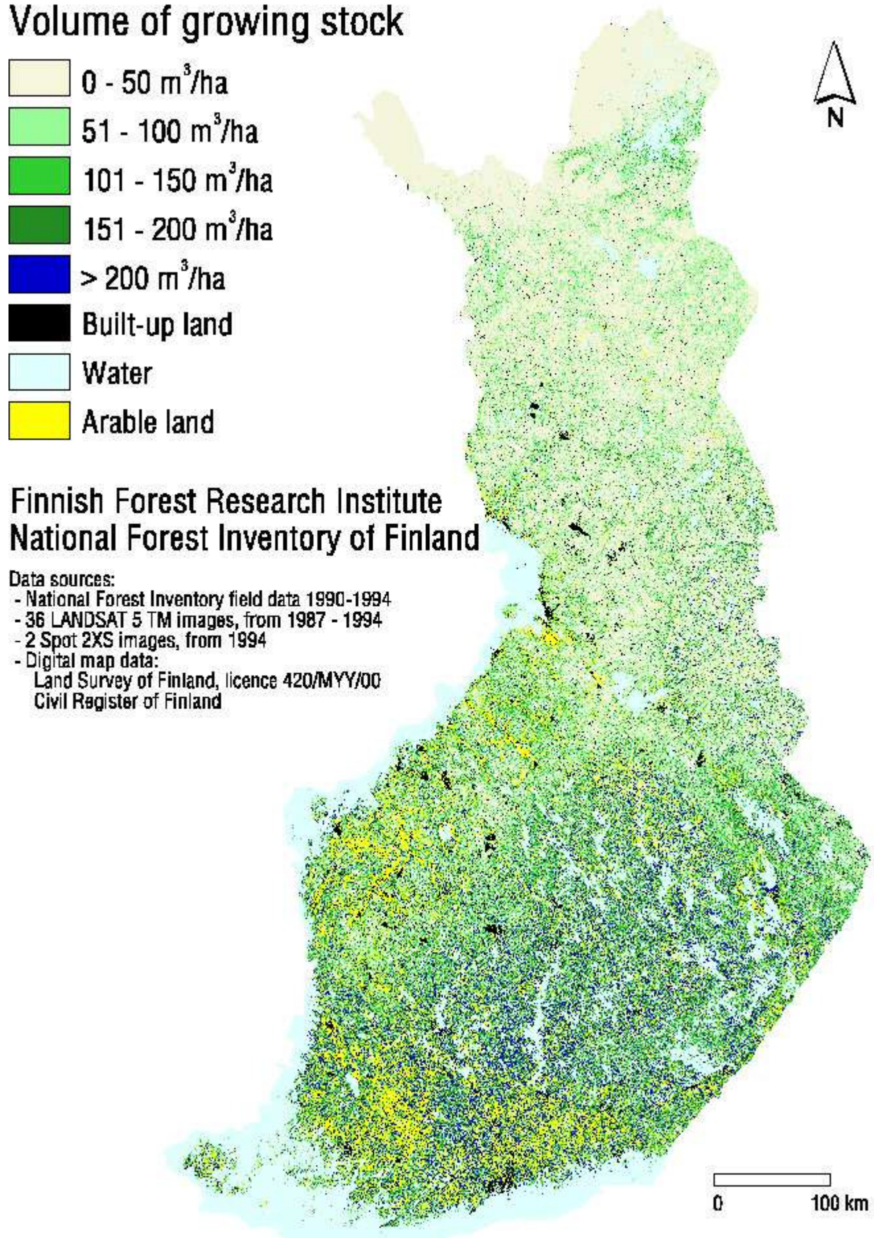

Figure 1: An example of a wall-to-wall output map of the Finnish multi-source national forest inventory, the volume of growing stock. Note that the classification has been done for map colouring. The unit in the original data is 1 m^3/ha.

c) total tree stem volume of growing stock (m^3),
d) mean volume of saw timber (m^3/ha),
e) total volume of saw timber (m^3),
f) mean tree stem volume of OBL (m^3/ha) and
g) total tree stem volume of OBL (m^3).

The estimates of parameter values on the multi-source inventory output maps are: forestry land 26.42045 million hectares, total volume of all species 2059.1 million m^3, mean volume of growing stock on forestry land of all species 77.9 m^3/ha with a standard deviation of volumes among pixels 68.3 m^3/ha, the total volume and mean volume of OBL species on forestry land 62.44 million m^3 and 2.4 m^3/ha respectively, and the total and mean volume saw timber 613.8 million m^3 and 23.23 m^3/ha respectively.

The simulation was done for all designs as follows. The starting point was selected randomly within a square corresponding to the distances in south-north and west-east directions of two adjacent clusters or the distance of two adjacent sample plots in Eurogrid. For all designs, 1000 samples were selected. The estimate of the parameter of interest, e.g., total volume, were computed from each sample. The mean of the estimates of the parameter values as well the standard deviation over samples were also computed,

$$\text{sd} = \sqrt{\frac{\sum_{j=1}^{n}(y_i - \bar{y})^2}{n-1}} \qquad 2$$

where y_i is the estimate of the parameter in i^{th} simulation and $\bar{y}$ the average of the estimates over the simulations.

On the basis of sampling error definition, the standard deviation (2) can be used as sampling error.

The goal was to find two groups of sampling designs, a dense design group and a sparse design group, in such a way that the errors of the estimates by parameters and by groups were of about the same magnitude. This was achieved through several sampling simulations using a method of trial and error. The starting design for the dense design was a grid of detached plots with the distances of 4 km$\times$4 km (Eurogrid), and for the sparse design, the NFMA design with a NFMA type cluster on every crossing of latitude and longitude.

The two groups which fulfill the given criteria, dense and sparse, and the final designs for which the costs were calculated were as follows:

1. A dense NFMA design, a NFMA tract distances in latitude and longitude are 1/14 and 1/7 degrees respectively.

2. A dense grid of detached plots with intervals of 4 km $\times$ 4 km, called here a dense Eurogrid.

3. A dense cluster design, a cluster consisting of 12 plots located on the sides of a half rectangle with a distance of 300 m apart from each other, and with cluster distances of 10 km $\times$ 10 km (Cluster, no stratification).

4. A dense stratified cluster design the clusters of the plots as in point 3, but the distances between clusters varied in different parts of the country between 10 km $\times$ 10 km and 15 km $\times$ 15 km (Cluster, stratification). In the final design, the cluster distances by regions were from South to North 10 km, 10 km, 11 km, 12 km, 13 km and 15 km (Figure 2).

5. A sparse NFMA design, a NFMA tract distance in both latitude and longitude is one degree.

6. A Sparse grid of detached plots with the intervals of 37 km $\times$ 37 km, called here a sparse Eurogrid.

7. A sparse cluster design, a cluster consisting of 12 plots located on the sides of a half rectangle (Figure 2) with a distance of 300 m apart from each other and with cluster distances of 80 km $\times$ 80 km (Cluster, no stratification).

In design 4, the country was divided into five sub-regions using lines parallel to latitudes (Figure 2). The reason is that mean volume of growing stock decreases from South to North and also that land-use class variability decreases from South to North. An efficient sample is, thus, such that the sampling density is higher in the south and lower in the north. The whole country is located in the national geographic system between latitudes 7779725 and 6608750 (metres from the Equator). The four latitude lines dividing the country into the sub-regions were located at the distances of 7601225, 7347725, 7032725 and 6836225 metres (Figure 2).

3.2 Time consumption in the field work of different sample designs

In this study, the time used by a field crew to measure a field plot or a cluster of field plots was divided to several phases. First of all, two kinds of field

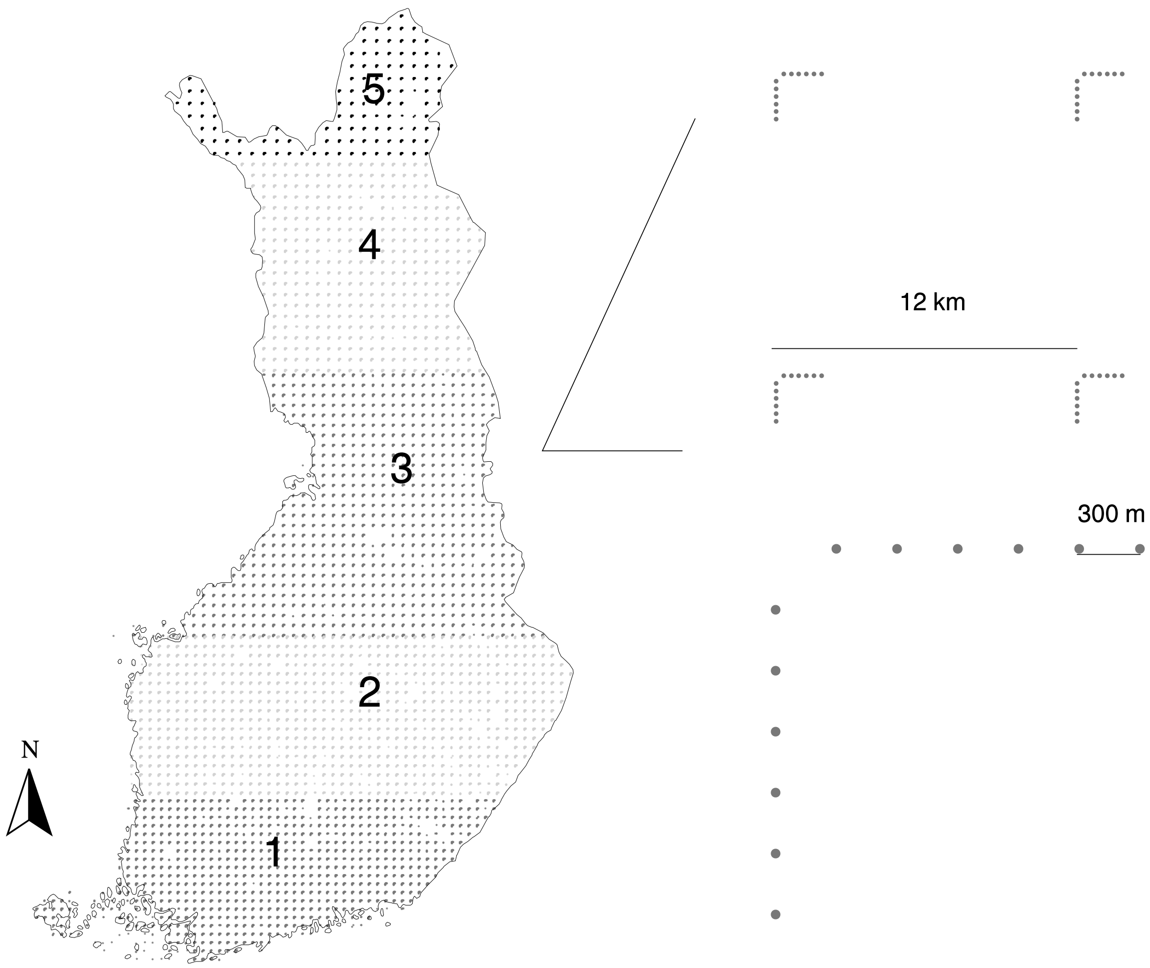

Figure 2: Five geographic regions used in the study for stratified cluster-wise sampling design, with cluster distances from 10 × 10 km to 15 × 15 km, and with an example of cluster distances for region 3 (distances of 12 × 12 km), as well as the shape of the cluster in all cluster-wise designs.

plot measurements were considered: 1) FAO NFMA tracts and fieldwork and 2) Finnish NFI field plot measurements. The time (minutes) needed for each phase in both type of field work was based on earlier studies in the Finnish NFI (Päivinen and Yli-Kojola 1983, Henttonen 1991) and to practical experiences in the NFI9 (1996-2003) and NFI10 (2004-2008). Several assumptions were made to get the time costs of different sample designs comparable: The walking speed with GPS device in the field and the daily lunch break in the field were assumed to be the same in all the different designs. Two sets of average distances (i.e. driving times) from the lodgment of the field crew were used, one for the sparse and another one for the dense sampling designs.

3.2.1 NFI field plot

The measuring of the temporary NFI field plot on forest and poorly productive forest (in this case FRYL mask) consists of measuring tally trees, and sample trees and assessing the field plot stand variables. The field crew consists of three persons. The components of the field work for both Eurogrid and systematic cluster samples of L-shape, for 1) dense and 2) sparse sampling designs studied are presented in Table 1.

Table 1: Estimated time costs for different working components in Eurogrid and systematic cluster sampling for 1) dense and 2) sparse sampling designs in different regions of Finland (Figure 2).

Region	Driving				Walk in the field	Measuring a plot		Daily pause
	to first plot/cluster		to subsequent plots ⊠			forestry land	other land	
	4×4–37×37	80×80 km	4×4,	37×37 km				
	minutes				min/km	minutes		
1 (South)	40	50	15	52	15	20	4	25
2	40	50	15	52	15	20	4	25
3	50	60	15	52	15	20	4	25
4	60	70	15	52	15	20	4	25
5 (North)	60	70	15	52	15	20	4	25

⊠ Eurogrid only

3.2.2 NFMA field plots

The time consumption for measuring the NFMA tracts was based on the estimated number of trees to be measured on NFMA plots of a size of of 20×250 m^2 and subplots SPL1 of a size of 10×20 m^2 on forest and poorly productive forest land (FPPF). The estimates of the average number of trees (stems/ha) in Southern Finland (approximately regions 1 & 2, Figure 2) and Northern Finland were based on the NFI9 data (Tomppo et al. 2008b). The estimates based on the NFI9 data were used for the number of the sawlog stems and the number of the trees with a DBH $\geq$ 5cm excluding sawlog. The land use class (LU) of the simulated plots and subplots was taken from MS-NFI9 output thematic maps; one pixel represents here a strip of 20×25 m^2 of the plot, possibly including the subplot of 10×20 m^2. The field crew for NFMA measurements was assumed to consist of four persons (crew leader, central line man, DBH measurer, height measurer). Apart from measuring trees, some extra time consumption was assumed separately for plots and subplots on FPPF. This assessment was based on time consumed for 'other actions' on temporary NFI7 field plots (Päivinen and Yli-Kojola 1983) and was applied to each pixel (20×25 m^2 of plot). A shorter time was assumed for assessment on other land classes than FPPF (zero time was used for water). The tract information, plot plan, LU and forest type assessments, as well as topographic and edaphic measurements on subplots, are expected to be collected by the crew leader at the same time when the tree measurements are carried out on plots and subplots on FPPF by the measurement assistants.

Table 2: Estimated time costs for different working components in NFMA sampling for plots and subplots in different regions of Finland (Figure 2).

Region	Driving		walk on field	*N* on FPPF		measuring a tree	other actions FPPF		other land	daily pause
	to first plot			saw log	DBH ≥ 5cm⊠		plot	subplot		
		14 × 7								
	minutes		min/km	trees/ha		minutes	minutes/25 m			minutes
1 (S)	50	40	15	113	1031	1	2.6	3.5	1.25	25
2	50	40	15	113	1031	1	2.6	3.5	1.25	25
3	60	50	15	43	734	1	2.6	3.5	1.25	25
4	70	60	15	39	738	1	2.6	3.5	1.25	25
5 (N)	70	60	15	27	740	1	2.6	3.5	1.25	25

⊠ excluding the sawlog stems

3.2.3 The driving times and distance from road to field plots

Only one way driving time to the first plot or cluster was included into the measurement time (working hours) following a common practice in the Finnish NFI. The lodgement is changed in few days intervals. The driving time (and packing the equipment) to the next plot for the Eurogrid of 4 km$\times$4 km and 37 km$\times$37 km is estimated using a driving speed of 50 km/h and 60 km/h, respectively and an estimated road distance $\sqrt{2}\times 4$ and $\sqrt{2}\times 37$ km. The walking speed from the road to the plot is equal to the speed along the tract (between plots in a cluster) because the GPS equipments are used to locate the plots.

The distance from the road to the field plot was estimated using the Finnish topographic database (National Land ... 1996). The Euclidean distance in geographical horizontal space from the nearest road point to the field plot or to the field plots in a cluster was calculated (Figure 3). Only field plots on land were considered. The walking distance from the road to a cluster was the distance from the road to the closest plot of the cluster, and in case of NFMA clusters, to the closest 25$\times$25 m^2 pixel of the cluster. For the L-shaped NFI clusters, the walking distance between the field plots was the distance along the tract line between the two furthermost field plots on land plus the Euclidean distance between them, i.e. the length of the sides of a triangle. For the NFMA clusters, the tract is walked around starting from the first tract pixel on land and ending at the last one on land plus the Euclidean distance between them. A coefficient of 1.3 was used to multiply all the walking distances to approximate the need caused by water areas and other obstacles. The plots on islands are usually reached by boat. This was not considered separately in the calculations.

4 Results

4.1 Error estimates

The error estimates and the measurement costs for the designs given in Section 3.1 are presented in this Chapter. The estimates for forestry land with standard errors and coefficients of variation (CV) are given for the dense grids in Table 3 and for the sparse grids in Table 4, those for mean and total volume estimates for dense designs in Tables 5 and 6, and for mean and total volumes estimates for sparse grids in Tables 7 and 8.

The densities of the designs are selected in such a way that the errors and the coefficients of variation by parameters are near each other on one hand in dense

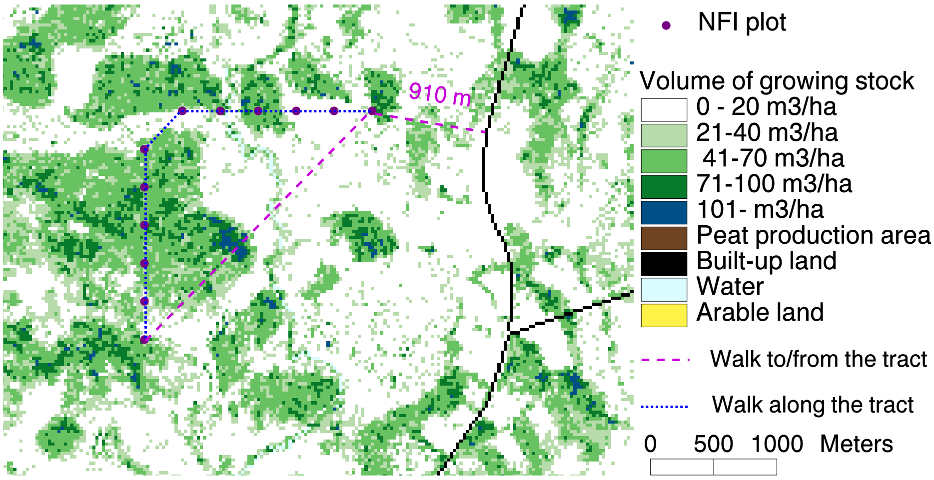

Figure 3: The minimum Euclidean distance (910 m) from the road to the closest field plot of a NFI cluster. The mean volume of growing stock of multi-source NFI9.

designs and on the other hand in sparse designs, see Chapter 3. The efficiencies can thus be compared in terms of the costs. The NFMA design with the distances of 1/14 and 1/7 degrees in latitudinal and longitudinal directions is the one comparable for the other designs, and will be used in the cost analysis. The error and CV of the area estimates are given also for a somewhat denser 'NFMA type grid', i.e, for a grid with a cluster distances of 1/20 degree in latitudinal direction and 1/10 degree in longitudinal direction in order to demonstrate how the error decreases when the density of the clusters increases (Table 3).

The errors of the estimates behave for different parameters in a somewhat different way and some small deviations can been seen in the errors. The CVs of the area estimates are slightly lower for Eurogrid and NFMA designs while the errors for mean volume and also total volume estimates are generally higher for Eurogrid and NFMA designs designs. Different behaviours are caused by the different spatial correlations of the variables. It is not possible to find designs whose error estimates by parameters are exactly equal.

The error estimates for forestry land areas for stratified and non-stratified dense sampling designs are near each other in spite of the lower density of non-stratified case (Table 3). This is caused by the fact that the area of other land than forestry land is low in the regions in which the low plot density is low. Random variation also affects the error estimates, particularly in the case of already small absolute errors for all designs. (The variations in errors are visible in sub-country level error estimates which are not given here).

Table 3: Forestry land area estimates, their standard errors and coefficients of variation for dense NFMA design, distances in latitude and longitude are 1/14 and 1/7 degrees respectively (and also 1/20 and 1/10 degrees), for Eurogrid (4 km × 4 km, detached points), for cluster design (cluster distance 10 km × 10 km) and for stratified cluster design (cluster distances 10 km × 10 km - 15 km × 15 km).

	Estimate	Standard error of estimate	Coefficient of variation (%)
Design	mill. ha	ha	%
NFMA 14x7	26.432	67079	0.254
NFMA 20x10	26.368	63269	0.240
Eurogrid	26.419	64945	0.246
Cluster	26.422	70877	0.268
Cluster, stratif	26.402	70268	0.266

Table 4: Forestry land area estimates, their standard errors and variation of coefficients for sparse NFMA design, distances in both latitude and longitude one degree, for Eurogrid (37 km × 37 km, detached points), for cluster design (cluster distance 80 km × 80 km).

	Estimate	Standard error of estimate	Coefficient of variation (%)
Design	mill. ha	mill. ha	%
NFMA	25.480	1.019	3.400
Eurogrid	26.586	0.669	2.515
Cluster	26.200	0.627	2.394

The estimates of the mean volume of growing stock of all species (ALL), other broad leaved species than birch (OBL) and sawtimber (Saw), their standard errors

Table 5: Mean volume estimates for growing stock (ALL), for broad leaved tree species other than birch (OBL) and for sawtimber (Saw), their standard errors and variation of coefficients for dense NFMA grid (distances in latitude and longitude are 1/14 and 1/7 degrees respectively), for Eurogrid (4 km × 4 km, detached points), for cluster design (cluster distance 10 km × 10 km) and for stratified cluster design (cluster distances 10 km × 10 km - 15 km × 15 km). OBL estimates are calculated using either whole plot (Plot) or sub-plot 1 only (SPL1).

	Estimate			Standard error of estimate			Coefficient of variation (%)		
Design	m^3/ha			m^3/ha			%		
	ALL	OBL	Saw	ALL	OBL	Saw	ALL	OBL	Saw
NFMA (OBL, Plot)	78.04	2.36	23.25	0.439	0.0300	0.215	0.563	1.272	0.923
NFMA (OBL, SPL1)	78.04	2.36	23.25	0.439	0.0359	0.215	0.563	1.520	0.923
Eurogrid	77.94	2.37	23.23	0.457	0.0493	0.247	0.586	2.083	1.063
Cluster	77.95	2.39	23.39	0.417	0.0388	0.245	0.535	1.623	1.046
Cluster, stratif	78.33	2.38	23.54	0.441	0.0425	0.310	0.563	1.783	1.320

as well coefficients of variations for dense designs are given in Table 5. With the found sampling densities, the errors and CVs of the mean volume of all species (ALL) are slightly lower for stratified cluster designs than the errors for cluster design, Eurogrid and NFMA design. On the other hand, the errors and CVs for OBL estimates are slightly lower for NFMA design than for the other design. The stratified cluster design has lower density of the plots than the cluster design, wherefore the errors are slightly higher.

The error estimates for total volumes comprise the errors of the estimates of forestry land area and mean volumes (Table 6). The error estimates for the estimate of the growing stock is somewhat lower for cluster and stratified cluster design than for the other designs.

The overall conclusions of the sampling errors for the estimates concerning the dense designs are that they are near each other and the efficiency comparisons of the designs can be done by means of the costs. However, the error estimates of the volumes of the growing stock are usually lower for the entire growing stock

Table 6: Total volume estimates for growing stock (ALL), for broad leaved tree species other than birch (OBL) and for sawtimber (Saw), their standard errors and variation of coefficients for dense NFMA grid (distances in latitude and longitude are 1/14 and 1/7 degrees respectively), for Eurogrid (4 km × 4 km, detached points), for cluster design (cluster distance 10 km × 10 km) and for stratified cluster design (cluster distances 10 km × 10 km - 15 km × 15 km). OBL estimates are calculated using either whole plot (Plot) or sub-plot 1 only (SPL1).

	Estimate			Standard error of estimate			Coefficient of variation (%)		
Design	mill. m^3			mill. m^3			%		
	ALL	OBL	Saw	ALL	OBL	Saw	ALL	OBL	Saw
NFMA (OBL, PLot)	2062.9	62.414	614.5	14.321	0.810	6.419	0.694	1.300	1.044
NFMA (OBL, SPL1)	2062.9	62.406	614.5	14.321	0.964	6.419	0.694	1.545	1.044
Eurogrid	2059.1	62.492	613.8	13.738	1.321	6.817	0.667	2.115	1.111
Cluster	2059.5	63.047	617.5	12.827	1.018	6.414	0.622	1.614	1.039
Cluster, stratif	2068.0	62.963	620.5	12.444	1.115	7.602	0.602	1.770	1.225

estimates (both mean and total) for cluster designs, while of about the same magnitude or slightly lower for OBL, and in some cases for saw timber estimates for NFMA design. A much higher plot density of NFMA design seems to decrease the errors for these parameters.

When comparing the costs (time consumptions) in chapter 4.2 we see that cluster design, and particularly stratified cluster design, is much cheaper, and thus more efficient, than the designs of detach points (Eurogrid) and NFMA design.

The estimates of the mean volume of growing stock of all species (ALL), other broad leaved species than birch (OBL) and sawtimber (Saw), their standard errors as well coefficients of variations for sparse designs are given in Table 7, and the corresponding estimates and error estimates for the total volumes in Table 8. The cluster and plot densities were so low that estimates for the stratified cluster designs were not calculated for these densities.

A noticeable aspect is an obviously high bias for NFMA designs for the mean volumes, and thus also for the total volumes (Tables 7 and 8). The biases disap-

Table 7: Mean volume estimates for growing stock (ALL), for broad leaved tree species other than birch (OBL) and for sawtimber (Saw), their standard errors and variation of coefficients for sparse NFMA grid (distances in latitude and longitude are one degree in both directions), for Eurogrid (37 km × 37 km, detached points) and for cluster design (cluster distance 80 km × 80 km). OBL estimates are calculated using either whole plot (Plot) or sub-plot 1 only (SPL1).

	Estimate			Standard error of estimate			Coefficient of variation (%)		
Design		m^3/ha			m^3/ha			%	
	ALL	OBL	Saw	ALL	OBL	Saw	ALL	OBL	Saw
NFMA (OBL, Plot)	93.49	3.07	29.92	4.899	0.476	2.894	5.241	15.480	9.671
NFMA (OBL, SPL1)	93.49	3.08	29.92	4.899	0.538	2.894	5.241	17.488	9.671
Eurogrid	78.15	2.36	23.22	4.353	0.481	2.277	5.570	20.371	9.803
Cluster	78.13	2.36	23.37	3.763	0.367	2.031	4.817	15.427	8.692

peared when the cluster densities were slightly higher than one cluster at every crossing of latitude and longitude.

4.2 Total time needed and relative costs for different sample designs

The field plot measurement time and relative costs are presented for NFMA, Eurogrid and cluster designs, and for dense (Section 4.2.1) and sparse samples (Section 4.2.2). For the cluster designs and Eurogrid, the costs are estimated based on time consumption for measuring Finnish NFI sample plots and for the NFMA designs based on estimated time needed to measure the NFMA 'plots' 20×250 m^2 and 'subplots' (SPL1) 10×20 m^2 in boreal forests. The total time for measuring a plot in the Eurogrid design (4×4 km or 37×37 km) is the sum of driving time (from the lodgment or between plots), walking time from the road to a plot (twice the sum of distance multiplied by walking speed), measurement time of the field plot and the daily breaks. The time consumption is different for the first and the subsequent plots due to a different driving time. In the cluster designs, there is

Table 8: Total volume estimates for growing stock (ALL), for broad leaved tree species other than birch (OBL) and for sawtimber (Saw), their standard errors and variation of coefficients for sparse NFMA grid (distances in latitude and longitude are one degree in both directions), for Eurogrid (37 km × 37 km, detached points) and for cluster design (cluster distance 80 km × 80 km). OBL estimates are calculated using either whole plot (Plot) or sub-plot 1 only (SPL1).

	Estimate			Standard error of estimate			Coefficient of variation (%)		
Design	mill. m^3			mill. m^3			%		
	ALL	OBL	Saw	ALL	OBL	Saw	ALL	OBL	Saw
NFMA (OBL, Plot)	2381.1	78.308	762.2	158.2	12.439	77.05	6.643	15.882	10.11
NFMA (OBL, SPL1)	2381.1	78.318	762.2	158.2	14.035	77.05	6.643	20.843	10.11
Eurogrid	2066.2	62.788	612.5	132.9	13.087	64.01	6.434	20.843	10.45
Cluster	2065.1	62.273	617.8	116.4	9.622	58.09	5.636	15.452	9.40

additional walking time between the plots. The total daily working time is 435 minutes. The daily amount of plots measured by region (Figure 2) is obtained using the equation $integer((435 - t_{1st})/t_{subs}) + 1$ where t_{1st} is the time needed to measure the first plot during on a working day and t_{subs} the time needed to measure a subsequent plot on a working day. (Tables 9, 14 and 15).

For the cluster sampling designs and NFMA designs, the total amount of days needed to measure all the plots in a sample are calculated in such a way that the clusters are divided into two groups, 1) those which take either less than 350 minutes or more than 435 minutes, and 2) those which take more than 350 minutes but not more than 435 minutes. For the former ones, the total working time in days is obtained dividing the total minutes by 435. The latter clusters are considered to need one day each, i.e. a field crew will not continue to another cluster on that day. A possible need to return to the same cluster on another day (double driving and walking) is taken into account in the calculations. A field crew will, in practice, extend the day up to 600 minutes, at maximum, to complete the NFI or NFMA cluster in one day. If the time needed exceeds 600 minutes, a crew will return to the same cluster on another day.

4.2.1 Dense sampling designs –Eurogrid

Table 9: Estimated average working time per plot and total workload in systematic NFI plot sample (Eurogrid, 4 km × 4 km) in different regions of Finland.

Land use	Region	No. of plots	distance from road m	t_{1st}	t_{subs} minutes	No. plots per day	Total days
FRYL	1 (South)	2499	319	97	47	8	313
	2	4256	267	95	45	8	532
	3	4651	492	114	54	6	776
	4	3715	1678	170	100	3	1239
	5 (North)	1476	8776	447	377	1	1476
Other land	1 (South)	984	117	74	24	16	62
	2	882	147	75	25	15	59
	3	517	140	84	24	15	35
	4	85	395	104	34	10	9
	5 (North)	4	1615	152	82	4	1
Total		19069					4502

The time costs per plot for systematic plot sample (Eurogrid, 4 km×4 km) applying NFI field plots are presented in Table 9, both for the first plots (t_{1st}) and subsequent plots (t_{subs}) on both FRYL mask plots and plots on the other land categories. Two different cluster sampling designs (with a cluster distances of 10 km×10 km) and stratified cluster design, both with NFI types of plots, were tested. The time consumptions are presented in Tables 10 and 11. Results were calculated also for a densified NFMA sampling design (distances in latitude and longitude are 1/14 and 1/7 degrees respectively) that uses different type of field plots (Table 12).

The results indicate clearly the lower time consumption of cluster design (cluster intervals 10 km×10 km) and stratified cluster design compared to Eurogrid. The needed time is 82 % and 59 % of that of Eurogrid, respectively. If each cluster would be measured in one day, independently of the length of working hours, the time consumption of the cluster design and stratified cluster sampling would be 76 % and 56 % of that of Eurogrid, respectively. The differences are signif-

Table 10: Estimated average working time (t) per cluster and total workload in systematic cluster sampling of 10×10 km and 12 NFI plots per cluster in different regions of Finland.

Region	No. of clusters	No. of plots	distance from road	cluster	Total days		
					$t < 350$ min. or $t > 435$ min.	350 min. $< t <$ 435 min.	All
			m	minutes			
1 (South)	693	6693	374	338	256	316	572
2	969	9723	93	348	226	601	827
3	929	10133	123	394	456	418	864
4	629	7165	1095	496	564	161	725
5 (North)	277	2883	7928	1117	684	30	714
	3497	36597	957	445			3712

icant, especially in Northern Finland (Lapland), regions 4 and 5, where the road network is sparse.

A large number of NFMA clusters were needed (6228) to achieve the same error level as the other designs. The relative time consumption was 171 % of that of Eurogrid and 288 % of the stratified cluster design and 208 % of (unstratified) cluster design. Relative costs of densified NFMA are even higher when we take into account the assumed size of field crew 1+3 persons versus 1+2 for the other designs. Approximating the increase in salaries and other costs by a coefficient of 1.29 for NFMA, the relative cost of NFMA would be 220 % of that of Eurogrid and 372 % of the stratified cluster design.

The comparison is done based on the assumption that the country level standard errors of the estimates for variables of interest are approximately of the same magnitude in all sample designs.

It should be noted that the optimal cluster size should be, in practice, smaller in Northern Finland than in Southern Finland, because the average time cost clearly exceeds the 435 minutes daily working time in the North due to long walking and driving distances. The driving costs paid to the car owner in a field crew would be higher in the Eurogrid design than in the other designs. On the other hand, it is possible that a field crew has to change the lodging more often in the cluster

Table 11: Estimated average time cost per plot and total workload in stratified systematic cluster sampling of 10×10 km to 15×15 km cluster distances and 12 NFI plots per cluster in different regions of Finland.

Region	No. clusters	No. of plots	distance from road to cluster	cluster	Total days		
					< 350 min. or > 435 min.	350 min. < time < 435 min.	all
			m	minutes			
1 (South)	696	6727	480	347	257	332	589
2	802	8211	89	354	190	505	695
3	662	7319	197	400	319	315	634
4	384	4314	1099	491	346	93	439
5 (North)	119	1289	8081	1148	302	14	316
	2663	27860	721	419			2673

design which will add some extra cost to these designs. The transition time from one region to another has not been taken into account in the calculations. It is also assumed that the entire sample (all plots) is measured in one year, and not, e.g., every fifth cluster/plot in a year.

4.2.2 Sparse sampling designs –NFMA

The measurement time per NFMA cluster and total time needed to complete a sample are presented in Table 13. The similar measurement time for a Eurogrid sample (systematic plot sample of 37 km×37 km) applying NFI field plots are presented in Table 14. The measurement time for the first plots (t_{1st}) and subsequent plots (t_{subs}) are included, both for plots on FRYL mask and for plots on other land. The measurement times were also calculated for the same sampling design, Eurogrid, (37 km×37 km) assuming NFMA type measurements (Table 15). For each pixel on land on the output map, NFMA type plot measurements (tree measurements on FPPF) on a plot of 20×25 m^2 and on a subplot of 10×20 m^2 had to be made. Time for tree measurements was counted on FPPF pixels based on MS-NFI map data (cf. Table 2). Note that the unproductive forest land is allocated

Table 12: Estimated average working time (t) per cluster and total workload in dense NFMA grid 1/14 °× 1/7° sampling in different regions of Finland.

Region	No. of clusters	No. of pixels	distance from road	cluster	Total days		
					$t < 350$ min. or $t > 435$ min.	350 min. $< t <$ 435 min.	All
			m	minutes			
1 (South)	1104	35364	438	479	1080	152	1232
2	1652	56724	92	547	1911	176	2087
3	1644	61512	273	419	1264	352	1616
4	1284	49360	1473	514	1317	216	1533
5 (North)	544	19928	8489	993	1171	80	1251
	6228	222888	1219	533			7719

to other land on Table 15, wherefore the number of plots on other land as well as average distances from the road differ from those in Table 14.

The third sparse design analysed was a cluster sampling design with a cluster distances of 80 km×80 km and with 12 NFI field plots with intervals of 300 m. Time consumptions are presented in Table 16. Equally, the time costs were calculated assuming NFMA field measurements for each pixel sampled (Table 17).

For the sparse sampling designs, the NFMA sampling design costs were higher than for the Eurogrid design (37 km×37 km) or cluster design (80 km×80 km, 12 plots). The costs of Eurogrid and cluster design with NFI types of plots were 94 % and 71 % (73 % using 10 simulations in Tables 13 and 16), respectively, of the time of NFMA design. Approximating that the daily costs of a NFMA crew is 1.29 times of the costs of the other designs, caused by bigger field crew, the costs of the Eurogrid would be 71 % of the costs of NFMA design, and the costs of the cluster design 55 % of the costs of the NFMA design.

If NFMA type field measurements (plot and subplot) were assumed for each pixel sampled in systematic and cluster samplings, the time costs were 100 % and 74 % of the NFMA sampling time consumption, respectively.

The comparison is done based on the assumption that the country level standard errors of the estimates for variables of interest are approximately of the same

Table 13: Estimated average working time (t) per cluster and total workload in NFMA cluster sampling in different regions of Finland.

Region	No. of clusters	No. of pixels	distance from road	cluster	Total days		
					$t < 350$ min. or $t > 435$ min.	350 min. $< t <$ 435 min.	All
			m	minutes			
1 (South)	10	370	652	539	12	1	13
2	18	620	92	558	24		24
3	18	682	430	465	17	3	20
4	12	477	2101	604	17		17
5 (North)	4	136	4714	419	4		4
	62	2285	968	528			78
10 simulations							79.4

magnitude in the three sample designs. In practice, the NFMA cluster should be smaller or the field crew larger because the average measurement time clearly exceeds the 435 minutes daily working time. Extended working hours may be accepted occasionally only. This concerns to some extent the 80 km× 80 km systematic clusters too, especially in Northern Finland. The higher driving costs of Eurogrid noted in section 4.2.1 concern also the sparse sampling designs. It should be noted that costs were calculated for a single simulated sample and there is large random variation in the costs for sparse samples. A more precise cost estimate can be obtained repeating the sampling and re-calculating the costs several times (Tables 13 and 16).

Table 14: Estimated average working time per plot and total workload in systematic NFI plot sample (37×37 km) in different regions of Finland.

Land use	Region	No. of plots	distance from road m	t_{1st}	t_{subs} minutes	No. plots per day	Total days
FRYL	1 (South)	29	435	102	88	4	8
	2	54	271	96	82	5	11
	3	58	468	113	90	4	15
	4	42	2302	195	161	2	21
	5 (North)	13	9194	464	430	1	13
Other land	1 (South)	14	70	72	58	7	2
	2	6	162	75	62	6	1
	3	6	242	88	65	6	1
	4	5	23	90	56	7	1
	5 (North)						
Total		227					73

5 Conclusions and discussions

We have presented a method to estimate sampling errors and measurement time of a sample to estimate forest inventory parameters using a simulation with the data based on output forest maps of a multi-source inventory.

The method has been applied with the the selected parameters to sampling designs with two levels of sampling errors of 1) the error level that correspond to the design and plot configuration employed by UN/FAO in NFMA, except that the tract distances are 1/14 degrees in latitude distance and 1/7 degrees in longitude distance, 2) the error level of UN/FAO NFMA design, i.e., the tract distances are one degree in both directions. The first group of the designs are called here 'dense designs' and the second group 'sparse designs'. The dense design has been selected in such a way that sub-country level parameter estimates with acceptable sampling errors can be obtained from field measurements.

The alternative designs are: a) grid of detached plots, called Eurogrid, with the plot intervals of 4 km × 4 km for the dense design and 37 km × 37 km for the sparse design, b) a cluster design (without stratification), 12 field plots on a cluster,

Table 15: Estimated average working time per plot and total workload in systematic sample (37×37 km) applying NFMA plot (20×25 m^2 plot and subplot) in different regions of Finland.

Land use	Region	No. of plots	distance from road m	t_{1st}	t_{subs} minutes	No. plots per day	Total days
FPPF	1 (South)	27	142	100	87	4	7
	2	52	266	105	92	4	13
	3	55	431	112	89	4	14
	4	33	2039	185	152	2	17
	5 (North)	3	2297	194	161	2	2
Other land*	1 (South)	16	609	90	77	5	4
	2	8	224	75	62	6	2
	3	9	544	97	74	5	2
	4	14	2108	168	135	2	7
	5 (North)	10	11263	526	493	1	10
Total		227					78

* includes unproductive forest land

with a plot distance of 300 m, and with the same cluster distances over the entire country, 10 km × 10 km for the dense design and 80 km × 80 km for the sparse design, c) NFMA design with a cluster distances for dense and sparse designs as given in the previous paragraph, and d) stratified design, with the cluster distances varying from 10 km × 10 km to 15 km × 15 km (only dense design version).

All the designs have been selected in such a way that in the two design groups, dense and sparse, the error estimates for the parameters 1) forestry land, 2) mean and total volumes of growing stock (all tree species), 3) mean and total volumes of other broad leaved tree species than birch (representing a rare event) as well as 4) the mean and total volume of saw timber, are about the same size within a density group. The efficiencies can thus be compared in terms of the respective costs only.

The needed field crew days and the relative costs to measure the entire country of Finland and covering all land use classes are presented in Tables 18 and 19, and Figure 5.

For the cost calculations, it has been assumed that a field crew consists of one

Table 16: Estimated average working time (t) per cluster and total workload in systematic cluster sampling of 80× 80 km and 12 NFI plots per cluster in different regions of Finland.

Region	No. of clusters	No. of plots	distance from road	t cluster	Total days		
					t < 350 min. or t > 435 min.	350 min. < t < 435 min.	All
			m	minutes			
1 (South)	10	95	503	356	4	5	9
2	18	193	30	384	4	14	18
3	13	144	225	411	11	2	13
4	9	98	1148	502	10	1	11
5 (North)	3	31	1000	451	3	1	4
	53	561	412	409			55
10 simulations							58.3

Table 17: Estimated average working time (t) per cluster and total workload in systematic cluster sampling of 80× 80 km and 12 NFMA plots (20× 25 m^2 plot and subplot) per cluster in different regions of Finland.

Region	No. of clusters	No. of plots	distance from road	t cluster	Total days		
					t < 350 min. or t > 435 min.	350 min. < t < 435 min.	All
			m	minutes			
1 (South)	10	95	503	416	8	2	10
2	18	193	30	479	18	3	21
3	13	144	225	391	7	6	13
4	9	98	1148	468	6	5	11
5 (North)	3	31	1000	336	2	1	3
	53	561	412	436			58

plus 2 members for other designs except NFMA design for which the crew size is

Table 18: The field crew days and the relative costs to measure the entire country of Finland, covering all land use classes, dense designs.

Design	Crew days	Relative time	Relative cost
Stratified cluster design	2773	1	1
Non stratified cluster design	3712	1.39	1.39
Eurogrid	4502	1.68	1.68
NFMA	7712	2.89	3.72

Table 19: The field crew days and the relative costs to measure the entire country of Finland, covering all land use classes, sparse designs.

Design	Crew days	Relative time	Relative cost
Non stratified cluster design	55	1	1
Eurogrid	73	1.32	1.32
NFMA	78	1.41	1.82

one plus three members.

The design in which the density of the plots varies depending on the variation of the forests is the most efficient one. The NFMA approach needs resources almost four times as much as the stratified cluster design.

The differences in the costs between different design for sparse sampling designs are lower than those for the dense designs. The reason is that for all designs, a relatively large amount of time is spent moving from one site to another or from a lodgement to a cluster/plot. The costs for the cluster design are, however, clearly lower than the other designs.

These obtained results clearly favour cluster designs, particularly with stratification.

The explanations are that, in case of Eurogrid, a large amount of time is needed in traveling from one observation site to another.

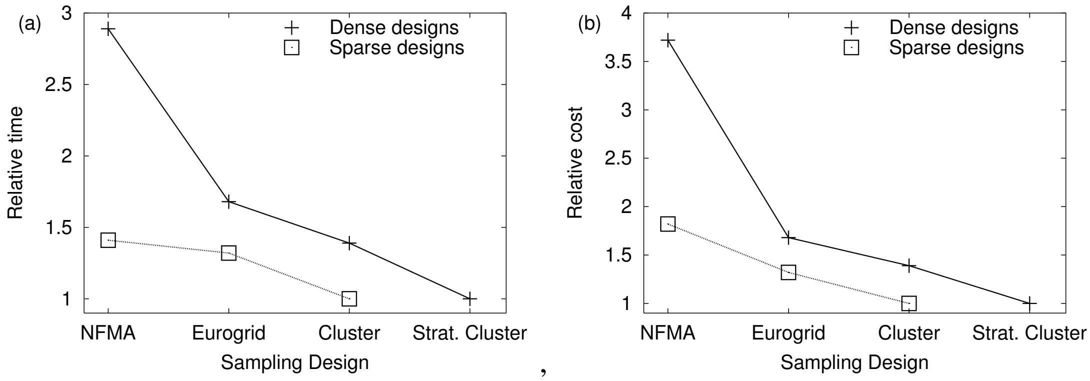

Figure 4: The relative time consumption (a) and costs (b) to measure entire Finland in different sampling designs.

For the dense designs, the time consumptions for non-stratified and stratified cluster-wise designs were 76 % and 56 %, respectively, of the consumption of Eurogrid.

The differences are significant, especially in Northern Finland (Lapland), in regions 4 and 5 where the road network is sparse (Figure 2).

The efficiency problem related to NFMA design is that the measurements on a tract are carried out and observations recorded in a small area, resulting in measurements with a large amount of similar trees and land class observations with small variation. A large amount of the plots is thus needed in order to get competitive errors with the other designs. Spreading out the measurements for a larger area would increase the efficiency.

It should, however, be noted that the tests were carried out in Finnish forests. The results could be somewhat different for a different vegetation zone and in area with a different land use structure and forest structure. It could be expected, however, that somewhat similar conclusions can be obtained from the other regions.

Only a limited number of sampling designs were tested so far. The presented designs are just examples and do represent optimal designs, not even for the parameters in question. The purpose of the study is to demonstrate the methods that can be employed in finding an efficient sampling design. To find an 'optimal design' for the entire country would need many more tests.

One should also bear in mind that the optimization of a sampling design is a complicated task. Different parameters may require different designs. However, the tested basic parameters should give a good picture also for other parameters.

All the results should be considered as preliminary, and the work will be continued. However, we believe that a similar study can be extended outside of Finland, and also using other type of forest, land use and land cover data presented in a map form.

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