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Sampling Methods, Remote Sensing and GIS Multiresource Forest Inventory

With 113 Figures, 5 in Color and 27 Tables

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Preface

When we talk about forests, we talk about 30% of our planet's land surface area. In 2000 there was an estimated 3 870×10^6 ha of forest worldwide, of which 5% is in forest plantations and 95% in natural[1] forests (FAO 2003). Forests are not only a source for timber; they also generate significant nonwood goods and services, mitigate climate change, conserve biological diversity, provide protection from natural hazards, and not least: provide recreational areas for an increasingly urbanized world population. The availability of timber and nonwood goods and services is waning as deforestation and degradation of tropical forests continue. While forest area has stabilized or is slightly increasing in the boreal and temperate regions, the annual loss of forest area in the tropics and subtropics is decreasing. Between 1990 and 2000 the annual rate of deforestation was estimated to be 14.6×10^6 ha (approximately 0.38%) and took place mainly in tropical and subtropical forests (FAO 2003). The net annual rate of change is about 9.4×10^6 ha (0.2%).

Maintaining and enhancing forest areas and the vitality of forest ecosystems is a widely accepted political goal, which is often opposed by conflicting demands of various stakeholders. Solutions to conflicts of this nature require actions at different scales ranging from managing demands of local communities to resolutions of transboundary problems such as global climate change (Jackson and Ingeles 1998; Mayers and Bass 2004; Sliggers and Kakabeeke 2005). Decisions about political measures as well as local management issues will not be effective unless they rest on reliable, timely, and readily available information. Forest inventories offer a tool to provide objective and reliable information about the multiple functions of forest ecosystems and their potential to satisfy various demands.

There is always a direct relation between the quality of information available and the cost involved in obtaining it. The complexity, diversity, and wide spatial extension of forests preclude a 100% assessment in most cases. An alternative to a complete enumeration is sampling, which is the process of obtaining information by assessing only a proportion of and drawing inference for the

[1] In the FAO terminology "natural" includes both managed and unmanaged forests.

whole. Where spatial information is to be provided, remote sensing offers a suite of methods.

This book is intended to be a primer on multiresource forest inventories, with special reference to tropical and subtropical forests. The focus is on sustainable forest management, which requires an assessment of both the current state and changes over time. The information needs to be satisfied by forest inventories cover a wide range, which extends far beyond the forests' productive function and timber supply. Nonwood goods and services, environmental functions – such as mitigating climate change – biodiversity, watershed protection, protective functions, or recreation are related issues.

Besides the diversity of topics, the size of the area for which information is required is to be considered when designing and implementing a forest inventory. Local assessments require different approaches from regional, national, or multinational assessments. While field assessments may be a sufficient data source for inventorying and monitoring small areas, extensive inventories for large areas may involve the combination of different data sources for reasons of cost-effectiveness. Thus, remote sensing has become a prominent tool for multiscale forest resources assessments (Franklin 2001; Wulder and Franklin 2003).

Today's information needs about the forest resource often touch on areas outside the forests as well. For example, information on the accessibility of forest areas, road network inside and outside forests, wildlife habitats at the edge of and in close proximity to a forest, and the protective function of forests. The forest is part of a larger landscape and its function and services can only be fully appreciated in an integrated multidiciplinary approach to forest inventory. The increasing availability of georeferenced data in digital format and the widespread availability of powerful geographic information systems (GIS) have greatly facilitated this integration and paved the way for cross-cutting spatial analyses of inventory information.

The short annotation above portends to the diversity of methods and approaches needed to carry out a multiresource forest inventory. It would be far beyond the scope of this book to give an overarching collection of available methods for forest resources assessments. Our intent is to give an introduction to and overview of basic concepts, which can be easily adapted for real-world situations.

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Contents

List of Abbreviations

AIC	Appreciation–influence–control
ALI	Advanced Land Imager
APA	American Pulpwood Association
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ATO	African Timber Organization
AVHRR	Advanced Very High Resolution Radiometer
AVIRIS	Airborne Visible Infrared Imaging Spectrometer
BLUP	Best linear unbiased prediction
CASI	Compact Airborne Spectrographic Imager
CBD	Convention on Biological Diversity
CCAD	Central American Commission for Environment and Development, Comisión Centroamericana de Ambiente y Desarrollo
CFI	Continuous forest inventory
CIFOR	Center for International Forestry Research
CIR	Color infrared
DBH	Diameter at breast height
DCMI	Dublin Core Metadata Initiative
DEM	Digital elevation model
DTM	Digital terrain model
EB	Empirical Bayesian
EBULP	Empirical best linear unbiased predictor
ECE	UN Economic Commission for Europe
EO	Earth observation/Earth Observer
ETM+	Enhanced Thematic Mapper Plus
EUNIS	European Nature Information System
FAO	Food and Agriculture Organization
FIFS	Forest industries feasibility study
FIS	Forest information systems
FMU	Forest management unit
fpc	Correction factor for the sampling fraction

FRCC	Fire regime condition class
FSC	Forest Stewardship Council
GCP	Ground control point
GIS	Geographic information systems
GPS	Global Positioning System
HH	Hansen–Hurwitz
HT	Tree height
ICP	International Cooperative Program
IGBP	International Geosphere and Biosphere Program
IPCC	Intergovernmental Panel on Climate Change
IRS	Indian Remote Sensing Satellite
IS	Importance sampling
ISRO	Indian Space Research Organization
ITTO	International Tropical Timber Organization
IUCN	International Union for the Conservation of Nature and Natural Resources (since 1990, the name "World Conservation Union" has been used)
IUFRO	International Union of Forest Research Organizations
ITTO	International Tropical Timber Organization
LCE	Linear contrast enhancement
MCAR	Missing completely at random
MCPFE	Ministerial Conference on the Protection of Forests in Europe
MERIS	Medium-Resolution Imaging Spectrometer
MIMICS	Michigan microwave canopy scattering model
MODIS	Moderate-Resolution Imaging Spectroradiometer
MS	Multispectral Scanner
MSE	Mean square error
MSR	Multiphase sampling with regression estimators
MSS	Multispectral Scanner
NALC	North American Land Characterization
NCDCDS	US National Committee for Digital Cartographic Data Standards
NDVI	Normalized-difference vegetation index
NFI	National Forest Inventory
NN	Nearest neighbor
NOAA	National Oceanic and Atmospheric Administration
NWGS	Nonwood goods and services
OLS	Ordinary least squares
PA	Population area
PCA	Principal component analysis
PLA	Participators learning and action
PPS	Probability proportional to size

PRA	Participators rural assessment
RBS	Randomized branch sampling
RGB	Red–green–blue
RRA	Rapid rural assessment
SAR	Synthetic aperture radar
SF	Spatial filtering
SFM	Sustainable forest management
SPOT	Système Pour l'Observation de la Terre
SPR	Sampling with partial replacement
SRS	Simple random sampling
TARA	Tarapoto Process
TBFRA	Temperate and Boreal Forest Resources Assessment
TM	Thematic Mapper
UNCED	United Nations Conference on Environment and Development
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework Convention on Climate Change
UTM	Universal Transverse Mercator
VI	Vegetation index
ZOPP	Objective-oriented project planning

Forest Inventories — an Overview 1

1.1 Focus

Forest inventory is a process for obtaining information on the quality and quantity of forest resources and forms the foundation of forest planning and forest policy. While early concepts of sustainable forest management and forest inventory focused on timber production (Hartig 1795; Cotta 1804), modern forest inventory concepts support a holistic view of forest ecosystems addressing not only timber production but also the multiple functions of forests as well as the need to understand the functioning mechanisms of forest ecosystems (von Gadow et al. 2002; Corona et al. 2003).

Forest resources assessment facilitates a multifaceted analysis and study of forests not only as an important source of subsistence, employment, revenue earnings, and raw materials to a number of industries but also for their vital role in ecological balance, environmental stability, biodiversity conservation, food security, and sustainable development of countries and the entire biosphere. Forests have to be managed judiciously not only for environmental protection and other services but also for various products and industrial raw material. In some parts of the world biological resources are being depleted faster than they can regenerate. Following the 1992 United Nations Conference on Environment and Development (UNCED) conference in Rio de Janeiro considerable progress has been made in the area of sustainable forest management. Among others, the International Tropical Timber Organization (ITTO) and the Forest Stewardship Council (FSC) developed criteria and indicators for sustainable forest management and certification. The Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC) describes measures to mitigate greenhouse gasses and addresses in Article 3.3 in particular the impact of deforestation and afforestation on global climate change. The Convention on Biological Diversity (CBD) that was ratified in 1994 deals with the protection and maintenance of biodiversity.

Forest resources assessments have their focus on the provision of information, which has several implications:

1. The information provided has to satisfy user needs. An inventory is generally not carried out for the needs of a single stakeholder; multiple issues of forests have to be covered. The objectives must be defined by those who require the data to be collected. All groups of users of inventory results should be involved in this phase of planning. Very often, the number of those interested in the inventory results increases after an inventory has already begun or after the findings have been published, so the data collected usually fail to satisfy all demands for information. Before defining the objectives it is advisable to make an inquiry not only among forest authorities but also among private forest owners, the wood-processing industry, land-use planning and environmental protection agencies, consumers of secondary forest products, wildlife organizations, and other potentially interested parties, thus enabling them to articulate their particular needs for information. In addition, this approach increases the possibility of finding partners who will make a financial contribution.
2. The information obtained by an inventory is typically presented in maps and statistical estimates. The basic concept of any statistical presentation is to summarize the population of interest and extract the facts important for potential users. This is generally done by presenting statistical parameters such as mean values, totals, or ratios and percentages. In addition, information on the variability or diversity of a population is an important ecological issue.
3. The information has to be objective. All parts of the population should be covered by the inventory; no part should be intentionally excluded. Data must be assessed in a nonsubjective way. Objective information requires the objective assessment of data. When information is gathered by some form of sampling, only application of a statistical design with known selection probabilities for any population element can ensure the integrity of the information-gathering process (inventory).
4. The information has to be reliable. The results of any sampling survey are always estimates rather than true values and are thus subject to a certain degree of uncertainty, as only part of the population is assessed. The uncertainty can be reduced through an optimal combination of sampling design and sample size in order to increase the precision of the estimates and to reduce sampling errors. The measurements themselves may be subject to error caused by, for example, inappropriate measurement devices, poor training, or subjective interpretation of measurement rules and definitions. Investments in improved instruments and the provision of intensive

training of field crews usually generate a handsome payback in the form of an increase in the quality and accuracy of data. It is necessary to specify the degree of precision and accuracy (see Chap. 3.4) to which the results should attain. This must be decided by the prospective users, though it is often difficult for administrators to think in terms of sampling error.

5. The information must be assessed in a cost-efficient way. Once forest managers and decision-makers have provided a rough definition of the objectives, several alternative inventory designs should be investigated. Alternatives can be based on different sampling design, sampling intensities, or data sources. Comparison of these alternatives allows assessment of the cost—benefit relationship and the final definition and weighing of the objectives.
6. The results of an inventory should be intuitively clear for potential users. Users are normally not very familiar with sampling statistics and thus the results should not require a Ph.D. in statistics for any immediate and basic interpretation. Users will have confidence only in information that they can understand. The inventory design should be documented and give advice for the impartial interpretation of data. As sample-based results are always subject to sampling errors, it is necessary to accompany any statistical estimate with estimates of sampling error or confidence interval.
7. Forest inventories should "only" present information in statistical and mapped format. It is beyond the mandate of a forest inventory to interpret results. However, forest inventory specialists should give advice for the interpretation of data. This restraint is also intended as a safeguard for the integrity of the inventory process.
8. In inventories on successive occasions, terms and definitions should not be changed unless it can be argued that the benefits outweigh the problems introduced by a change. When terms and definitions are changed between assessments one cannot distinguished between true change and change due to change in definitions.
9. Planning of a forest inventory is a complex task that involves expertise from many fields; thus, experts from silviculture, forest management planning, economics, policy, ecology, or timber products need to be consulted at an early stage.

1.2 Objectives

The main elements of an inventory depend very much upon the inventory objective; thus the objectives of an inventory have to be laid down in a very early phase of inventory planning. The exact definition is a joint action by the inventory designer and the potential user group. It is a very laborious