ISSN 1016-3263

International Union of Forestry Research Organizations
Union Internationale des Instituts de Recherches Forestières
Internationaler Verband Forstlicher Forschungsanstalten
Unión Internacional de Institutos de Investigación Forestal

IUFRO World Series Vol. 5

IUFRO Secretariat Vienna 1994

IUFRO International Guidelines for Forest Monitoring

Directrices Internacionales de IUFRO para la Monitorización de los Recursos Forestales

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A Project of
IUFRO Working Party S4.02-05

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Un proyecto del
Grupo de Trabajo de IUFRO S4.02-05

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Päivinen, Risto; Lund, H. Gyde; Poso, Simo; Zawila-Niedzwiecki, Tomasz. eds. 1994. **IUFRO International Guidelines for Forest Monitoring;**. A Project of IUFRO Working Party 4.02.02.**Directrices Internacionales de IUFRO para la Monitorización de los Recursos Forestales;** Un Proyecto del Grupo de Trabaho de IUFRO S4.02-5. IUFRO World Series Report 5. Vienna, Austria. International Union of Forestry Research Organizations. 102 p.

Recommended catalogue entry:
IUFRO International Guidelines for Forest Monitoring ; A Project of IUFRO Working Party S4.02-05 = Directrices Internacionales de IUFRO para la Monitorización de los Recursos Forestales ; Un proyecto del Grupo de Trabajo de IUFRO S4.02-05 / Risto Päivinen, H. Gyde Lund, Simo Poso and Tomasz Zawila-Niedzwiecki (eds.). Vienna : IUFRO, 1994. - 102p. - (IUFRO World Series , Vol. 5)

ISBN 3-901347-00-3

ISSN 1016 - 3263

FDC 585:587:(083.7)

Published and available from:
IUFRO Secretariat, Seckendorff-Gudent-Weg 8, A-1131 Vienna, Austria

Price: 30 US$

Translation and layout:
Gerda Wolfrum, IUFRO Secretariat Vienna

Printed by:
Hillebrand Nyomda KFT.
Sopron, Csengery U. 49
Hungary

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PREFACE

One of the major goals of the International Union of Forestry Research Organizations (IUFRO) is to improve communications among forest researchers and managers throughout the world.

The enclosed International Guidelines for Forest Monitoring outline a procedure to increase our ability to share plot information for research, management, inventories, and remote sensing verification. The intended users are those that conduct the collection of field data whether during the course of resource inventories or monitoring studies.

Following recommendations from the 1990 IUFRO World Congress in Montreal, IUFRO Subject Group S 4.02-05 (Remote Sensing and World Forest Monitoring) initiated work on the guidelines at the Wacharakitti International Workshop on Remote Sensing and Permanent Plot Techniques for World Forest Monitoring held in Pattaya, Thailand, 13-17 January 1992. Work on the guidelines was undertaken in cooperation with the Food and Agriculture Organization (FAO) of the United Nations.

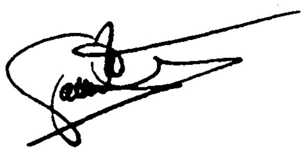
The guidelines were further refined following the Ilvessalo Symposium on National Forest Inventories held in Helsinki, Finland 17-21 August 1992. They were presented for review at the World Forest Watch meeting held in Brazil in May 1992, at the United Nations Environment Programme (UNEP)/FAO Expert Consultation on Environmental Parameters in Future Global Forest Assessments held in Nairobi in December 1992, at the World Resources Institute meeting on Defining Environmental Information Needs Early in the Next Century held in Washington, DC also in December 1992, and most recently at the FAO/Economic Community of Europe (ECE) Meeting of Experts on Global Forest Resources Assessment held in Kotka, Finland in May 1993. In addition, the guidelines were sent out to nearly 1,500 scientists, research organizations, and forest management agencies throughout the world for review.

The guidelines represent the input from those reviews and workshops. However, this report is not to be considered as the final result of the process. It should rather be regarded as a step towards improved information on our precious natural resources and will need follow-up and further development in the future.

Given this background and the need to be able to share information internationally, it is with great pleasure that I present these guidelines to you and urge all IUFRO member organizations and their scientists to follow the IUFRO International Guidelines for Forest Monitoring in their inventory and research activities.

I would like to congratulate and thank Dr. R. Päivinen and IUFRO Subject Group S4.02-05 for the effort in producing this guideline which I hope will help in global monitoring efforts.

Sincerely,



Dr. M. N. Salleh
IUFRO President

IUFRO International Guidelines for Forest Monitoring

A Project of
IUFRO Working Party S4.02-05

Editors:
Risto Päivinen, H. Gyde Lund, Simo Poso
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FOREWORD

The world's forests are the focus of international attention because of the many environmental issues being discussed today. In order to understand what is truly happening to our forest land, we need to monitor the resources to measure change and to predict change. Monitoring is the periodic observation of selected parameters for quantifying changes over time. We often use remote sensing and permanent plots to monitor changes in the forest resource base.

In order to share data and experiences among scientists in various parts of the world and to compare inventory data across regions, some form of international guidance is urgently needed. The purpose of these guidelines is to promote standardized or compatible collection and reporting of selected data for forest monitoring through cooperation in such a way that the results offer a common data base for research and management. We envisage that the results of individual forest resources surveys following these guidelines, would be transmitted to a global data base or made part of a network maintained by the United Nations. Contributors to the network would have access to the data base for the benefit of the designs of new surveys and assessments.

Additional copies of these Guidelines are available from the IUFRO Secretariat, Federal Forest Research Station, Seckendorff-Gudent Weg 8, A-1131 Vienna, Austria. The Guidelines will be reviewed in 1995 to reflect changing needs, priorities, and additional standards.

1. INTRODUCTION

1.1 Functions of the World's Forests

The Earth's forest resources provide vital food, fuel, and fiber for an increasing world population. Forests have provided resources for industrialization in many countries. They still play a very important role in providing sources for hard currency and as land reserves for increasing population, especially in developing countries.

Forests are both carbon sources and carbon sinks. They serve as filters for the air we breathe and the water we drink and they protect agriculture lands and residential areas from erosion, avalanches etc. Forests provide a critical habitat for diverse flora and fauna that may prove vital for human survival in the future. Furthermore, forests are places of recreation, worship, and strength for the inner body.

Unfortunately, the world's forest resources are dwindling at unprecedented rates in the tropics and losing diversity and productivity in some other regions. The rate, magnitude and impact of these changes are not known or understood.

1.2 Present Activities

Research scientists throughout the world collect data to study and model changes in the forest resources. National agencies conduct periodic inventories and assessments of their natural resources to develop broad land management policies and direction. To fulfil the mandate given in its constitution Food and Agriculture Organization (FAO) of United Nations collects, analyzes, interprets and disseminates information related to forests of the globe. Other organizations are making multi-country surveys of planetary carrying capacity and rates of change, including the United Nations Environment Programme (UNEP), the Economic Commission for Europe (ECE), the Joint Research Centre of the European Community (JRC/TREES), and others.

The results of this work are reported in various scientific and professional papers, national statistics and in the publications of the United Nations.

1.3 Problems

As noted above, there are several on-going forest assessment activities at the national, regional and global level. Many of these efforts are often uncoordinated and independent of one another. As a result, much available information is not known, is overlooked, or is not used. The use of different definitions and measurement methods may prevent the comparison of results. Major gaps in knowledge exist in large areas and duplication in others. Few countries have national forest inventories and existing inventories may not be suitable for monitoring changes or may not address the environmental issues we now face.

The establishment of a data base on global forest resources is essential. The data base will be promoted and its contents improved, to the degree that it can progressively include the results of other assessments wherever and whenever made. To implement this requires the compatibility of assessment results, which can be achieved by the application of certain methodological norms as provided by these guidelines.

1.4 Purpose of the Guidelines

All parties dealing with forest cover, biomass, quality and their change - researchers, national agencies and international organizations and cooperating nations - should be working towards a common goal to provide a complete picture of the status and trends of the world's forest resources.

The purpose of these guidelines is to promote standardized or compatible collection and reporting of selected data for forest monitoring through cooperation in such a way that the results offer a common data base for research and management.

The short term goals are to list data and define the variables that should be collected to address emerging forest and environmental concerns and to present the principles for collecting such data suitable for international use.

These guidelines will support the long term goal in global environmental information service: the establishment of a world forest resource information system. The expected end product would be a multi-nation network of databases, which if incorporated in their entirety, will provide forest resource estimates for the world.

1.5 Development of the Guidelines

In cooperation with the Food and Agriculture Organizations (FAO) of the United Nations, the International Union of Forestry Research Organizations (IUFRO) Working Party on Remote Sensing and World Forest Monitoring (S 4.02-05) has developed these guidelines.

The project was initiated at the IUFRO World Congress in Montreal in 1990. The basic input for these guidelines was developed at the Wacharakitti International Workshop on "Remote Sensing and Permanent Plot Techniques for World Forest Monitoring", sponsored by IUFRO S 4.02-05, and held in Pattaya, Thailand in January 1992. The work was continued by volunteer experts, and the next version of the guidelines was reviewed by IUFRO S 4.02-05 group after the Ilvessalo Symposium, held in Finland in August 1992. Over 100 scientists and remote sensing specialists from over 20 countries have contributed to these guidelines.

The main sponsor of this effort has been the Finnish International Development Agency FinnIDA. Other organizations contributing to the development work include: the University of Joensuu and University of Helsinki, Finland, Kasetsart University, Thailand, the European Forest Institute (EFI), Finland, and the United States Department of Agriculture (USDA) Forest Service Tropical Forestry Program.

1.6 Intended Users

The intended users of these guidelines are:

- those research scientists who collect forest resource information for modeling change and that want to share their data and have access to data of other scientists abroad.

- those who conduct resource inventories and monitoring efforts and wish to have their data compatible and comparable with similar efforts elsewhere. By following these guidelines, national and sub-national projects can ensure that they can compare their results with others and that their work can be utilized to compile regional results.

- those who fund monitoring efforts, such as aid agencies, that wish to ensure their data sets contain an internationally-recommended data set that are compatible with other donors. Donors can use these guidelines to make sure that their support to monitoring projects can be fully utilized.

- those who must aggregate data, such as FAO and ECE, for global or regional forest assessments. These guidelines developed in cooperation with relevant UN organizations will be tools in the work of those organizations in providing baseline data and forest resources classification standards. Thus they will serve in integrating global and national level resources monitoring activities.

The guidelines are presented in the sequence as they are to be considered in any monitoring project. As you use these guidelines, refer to them in your inventory and monitoring reports so others will know these standards were followed.

Recommended Reading

FAO 1993. Forest Resources Assessment 1990. Tropical countries. FAO Forestry Paper 112. FAO, Rome 1993. 60 p.

Jaakkola, S. 1992. International efforts at global forest monitoring using remote sensing. In: Lund, H.G., Päivinen, R. and Thammincha, S. chief eds. IUFRO S 4.02-05 Proceedings, Remote Sensing and Permanent Sample Plot Techniques for World Forest Monitoring. 13-17 January 1992; Pattaya, Thailand. Bangkok, Thailand; Asorn Siam; 13-23.

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UN-ECE/FAO 1992. The forest resources of the temperate zones. The UN-ECE/FAO 1990 forest resource assessment, Volume 1. General forest resource information. United Nations, New York, ECE/TIM/62. 348 p.

UN-ECE/FAO 1992. The forest resources of the temperate zones. The UN-ECE/FAO 1990 forest resource assessment, Volume 2. Benefits and functions of the forest, United Nations, New York, ECE/TIM/62. 268 p.

2. INFORMATION NEEDS

2.1 Information Needs Assessment

The first step in any monitoring effort is the information needs assessment (INA). "This is a critical phase of planning and one that has too often been neglected or, at best, kept hovering in the background" (Husch 1971). The important questions in the very beginning are: 'for what purpose?' and 'who will use the results ?'

The INA should be developed through consultation with interested parties - especially the potential users of the results.

From these questions and working partnerships with the end users, outlines of the results can be derived. They can be summary tables, graphs, geographical information, and statistical or other models. Knowing the techniques used for deriving the desired output, it is possible to decide the measurements needed in the field, and which other input data would be useful.

The importance of Information Needs Assessment cannot be overestimated. Whatever the scale of the monitoring effort is, the design should be started by specifying what one wants to know, and what one needs to infer from the collected information.

2.2 Forest Monitoring Levels

There are three basic levels where information needs are to be assessed; the local, the national and the global context. In all cases, results presented must respond to the information demand from researchers, professionals, politicians and the public. Janz (1993) has outlined three groups of uses for information on the global level, but these levels suit to other levels as well:

- creating awareness about state and development of forest and related resources
- monitoring and planning
- research on the supply potential and processes such as deforestation and climate change

At the international level the world's forests are viewed as the primary source of wood and non-wood goods and services providing commercial and non-commercial benefits. Equally, if not more important, forests are a major part of the biosphere influencing the carbon cycle and bio-productivity. Global issues involve biodiversity, forest health, site protection, climate change, and hydrology and water cycles.

Global needs for managing the natural resources are expressed in international pacts and recommendations. During UNCED in June 1992, new attention was paid to forest resources assessment. One programme area in Agenda 21 has the title "Establishing and/or strengthening capacities for the planning, assessment and systematic observations of forests and related programs, projects and activities, including commercial trade and process".

The objective is set "to strengthen or establish systems for the assessment and systematic observation of forests and forest lands with a view to assessing the impact of programs, projects and activities on the quality and extent of forest resources, land available for afforestation, and land tenure, and to integrate the systems in a continuing process of research and in-depth analysis while ensuring necessary modifications and improvements for planning and decision-making..." (see ie. Janz 1993).

In national forest inventories, sustained utilization of forest resources in a country is of primary concern. Forest area and its change as well as the balance between drain and growth estimates of the forest resources are factors that need to be high-lighted. The changes in soils and forest health etc. need to be investigated to ensure the utilization of resources in the future.

The third case is a local, sub-country forest information need; previously often needed for timber extraction. Now more often local information needs emphasize vegetation cover, land use pattern, soil quality etc. These characteristics are needed in the land use planning under population pressure. In this, social environment and local culture have to be noted as well.

Different monitoring approaches need different information, and therefore acquisition of the data may vary from project to project. Based on current global issues, the amount of forest cover, biomass production for carbon storage and sinks, rates of change of forests, forest quality and health are primary concerns at all levels.

Data which are common to all levels of decision making, make up a core data set (Lund 1986) that we encourage users of the guidelines to collect (see Tables 2-1 and 2-2). **The collection of the data given in tables 2-1 and 2-2 and according to the definitions given in Appendix 1 is essential to have an internationally consistent data base.**

Table 2-1 Information that may be needed at the local, national, and international levels for forest monitoring. The elements of the project are presented (***=highly important, **=medium importance, *=somewhat important. See also Husch, 1971):

	LEVEL OF MONITORING		
	Local Resource Studies	National Forest Inventory	Regional/Global Monitoring
FACTOR	IMPORTANCE		
Land use	***	***	***
Land cover	***	***	***
Land degradation	***	***	**
Site type	***	***	**
Soil type	***	***	**
Topography	***	**	**
Ownership	***	**	*
Accessibility	***	**	*
Biomass	***	***	***
Timber volume	***	***	**
Other forest products	***	***	*
Biodiversity	**	***	***
Forest health	***	***	***
Wildlife	***	**	*
Human impact	***	**	**
Watersheds	**	**	**

2.3 Types of Monitoring

In the following, some examples are given on the common variables that followers of this guide should collect for different types of monitoring projects.

The monitoring types are

1. land cover or land use - for land management
2. forest resources - for timber production
3. biomass - for energy use, carbon balance or developing local models
4. environmental quality or forest health - for ecosystem management

It must be underlined that these types seldom occur as such, often, monitoring activities combine data collection for a variety of purposes.

In land cover monitoring we are interested in the total land area, its present use, vegetation cover and its potentials if converted to other land use forms. Forest or forestry is only one land use form.

Table 2-2 Data needed for land cover, forest, biomass, and environmental quality monitoring. An X means the element is needed.

	Land cover	Forest	Biomass	Environ. quality
Plot Identification				
Location Coordinates	x	x	x	x
Elevation	x	x	x	x
Slope	x	x	x	x
Aspect	x	x	x	x
Terrain Position	x	x	x	x
Year Observed	x	x	x	x
Area Classification				
Land Use Class	x	x	x	x
Land Cover Class	x	x	x	x
Vegetation Type	x	x	x	x
Crown Closure	x	x	x	x
Stand History		x	x	
Area Classification Radius	x	x	x	x
Tree/Plant Ratings				
Species		x	x	x
Height		x	x	x
DBH/GBH		x	x	x
Age		x		
Growth		x	x	x
Stem Ratings				
Log Sizes		x		
Timber Quality		x		

Crown Ratings				
Crown Diameter			x	x
Crown Length			x	x
Leaf Area			x	
Defoliation		x		x
Bioindicators				x
Damages		x		x
Dendrochronology				x
Understory Vegetation		x	x	x
Foliar Chemistry				x
Soil Indicators	x	x		x

The definitions of these variables are presented in Appendix 1.

Most of the forest resources monitoring variables are useful for biomass estimation, and thus the conventional forest inventory differs from biomass estimation only in some extent. However, small trees, bush and shrubs and other than woody plants need special attention in biomass inventories.

In addition to the data on timber or biomass, the amount of change and direction of change (including growth, deforestation and degradation) are required in general. We also need to know the reason for change (fire,logging, poaching, shifting cultivation and data on species diversity, and the impact of population pressure).

Environmental quality includes ecosystem health, condition, and biodiversity of the vegetation, and the vital connections of the vegetation to other ecosystems. In measuring environmental quality, special bioindicators may be used.

Recommended Reading

Hunsaker and Carpenter. 1990. Ecological indicators for the Environmental Monitoring and Assessment Program. USEPA EPA/600/3-90/060.

Husch, B. 1971. Planning a forest inventory. FAO Forestry and Forest Products studies No 17. FAO, Rome 1971.

Janz, K. 1993. National inventories serving global monitoring of forest resources. Proceedings of Ilvessalo-symposium on National Forest Inventories. Finland, August 17-21, 1992. The Finnish Forest Research Institute, Research reports No 444. pp 108-115.

Kleinn, C. 1992. On the comparability of forest inventory results: the problem of compatible forest definitions. in: Wood and Turner (eds.): Integrating forest information over space and time, IUFRO Conference 13-17 January 1992. Camberra, Australia. p. 278-285.

Lund, H.G. 1986. A primer on integrating resource inventories. Gen. Tech. Report WO-49. Washington, DC: U.S. Department of Agriculture; Forest Service. 64 p.

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Wardle, P. and Padovani, F. 1990. Towards a common framework for world forest resource assessment. In: Lund, H.G. and Preto, G. eds. Proceedings - Global natural resource monitoring and assessments: preparing for the 21st century. 24-30 September 1989. Venice, Italy. Bethesda, MD: American Society for Photogrammetry and Remote Sensing; 714-733.

3. SOURCES OF INFORMATION FOR MONITORING

Much information exists in the form of maps, remote sensing and field information. Intuitively, one would want to take advantage of work already done. This is good advise providing that the new needs do not somehow compromise the existing system. In evaluating the existing information check for the information listed in the following:

3.1 General

- Location of where monitoring was conducted.

- Original purpose for the monitoring activity

- Forest cover or land cover and land use classes encountered according to FAO guidelines or scheme used (See Appendix 2).

- Description of additional data extracted and available.

- Date of observations - dates of previous observations and next observations if permanent plots.

- Statements of accuracy or quality control.

- Data base custodian - name, mailing address, telephone number and fax of person in charge of the data base. Indication if custodian is willing to disclose plot and/or plot data including trend information.

- Sources of supplemental data - remote sensing, aerial photography, field plots.

3.2 Map Data

Most areas on the globe are covered by maps. Although the scale, date, contents and accuracy of the maps may vary, they always provide a frame for planning the monitoring activities.

Most geographical features have the advantage of being rather permanent, like rivers, lakes and contour lines. Some other, like forested areas, roads and settlements may change over shorter periods of time. Map data can be employed in the planning of the monitoring, but especially in analyzing the monitoring data.

Procedures of data analysis at the simplest level involve comparing and combining specific maps. Such analysis can be carried out manually or, more efficiently, using computers. Computer based geographic information systems (GIS) technology provides an improved capability for analysis of the mapped data. The monitoring characteristics could be included in different databases and for forest purposes can be treated as the separate levels of information.

Ground and remotely sensed forest data can be integrated to these existing monitoring systems. GIS provide many useful functions, especially:

- map integration (information from maps of different scales, projections and legends could be combined),

- map overlay (for example remotely sensed data can be overlaid on a forest thematic map),

- spatial analysis.

3.3 Remotely Sensed Data

Remote sensing platforms and sensors vary from resampled AVHRR satellite imagery with four km resolution to hand-held video cameras in a fixed-winged aircraft with less than 1 m resolution. See Appendix 3 for a listing of remote sensors and their capabilities.

Instruments that generate images can be roughly listed as:

- photographic cameras employing various optic-film-filter combinations,

- video cameras (sometimes with filter combinations),

- scanning machines, which produce images in various bands simultaneously, exploring the target surface line by line from the visible to the thermal-infrared bands,

- radar systems, which employ the microwave portion of the electromagnetic spectrum, normally working in active mode: irradiating the surface to be investigated and capturing the reflected energy,

- laser machines.

For any remote sensing project, provide information on:

- Dates of coverage, calibration techniques.

- Information on bands/sensors used including a complete log of the processing that has been done to the data.

Aerial data

Aerial photographs in comparison with ground surveys offer a synoptic view from a large area of forest. Resolution of aerial photos permit very detailed analysis and on the other hand, give the possibility of exploring hard-to-reach areas where a field survey would require heavy logistical support and might cause climatic, environmental or political problems.

Aerial photography offers some advantages like:

- a broad range of films in visible and infrared portions of the spectrum and a high level of film technology, coupled with a broad choice of flight heights, providing a variety of scales (from very large with high resolution to small for general recognition purposes),

- relatively low cost of survey,

- no need of sophisticated processing techniques,

- realistic representation of features, making the interpretation a natural process,

- metric reliability and possibility of precise measurements,

- stereoscopic viewing.

Interpretation of aerial data allow the recognition and mapping of the different forest types, monitoring of evolution and the assessment of damages and of stress condition.

According to the type of survey, the most suitable scale must be selected to detect the characteristics of the investigated forests. Scales smaller than 1:30000 can be used for regional mapping and scales between 1:30000 and 1:10000 can be used for detailed mapping of forests as well as for identification of type of forests and assessment of damage. Scales larger than 1:10000 are used for very detailed monitoring and mapping, including single tree assessments.

Satellite data

For an overview at the continental scale, AVHRR data with its 1- km resolution and daily overpass would be most cost-effective with reasonable accuracy. Existing vegetation type, Forest/Non-Forest and other similar coarse classification at scale 1:500000 or less is possible using 1-km LAC data.

For forest monitoring and general cultural features Landsat MSS, TM and SPOT are recommended. Landsat MSS data have an advantage in being the oldest satellite data for land characteristic estimation, making a retrospective image interpretation possible back to 1972. Landsat TM have a wide spectral range with 7 channels; with 3,4 and 7 often favored for vegetation studies, including forest health assessment. SPOT has the best spatial resolution in digital satellite data.

These satellites register images in the optical range of the electromagnetic spectrum, so cloud cover persistence is a major obstacle in data capture. However, microwave (radar) satellite - existing (ERS-1, JERS-1, ALMAZ) and future (Radarsat) - could constitute a very strong support for forest monitoring.

The main advantages of the satellite data are:

- frequent observations throughout the globe

- digital format makes automatic interpretation possible

- standardized and controlled measurements in time and space

- low cost per area unit

The major satellite operators (such as NOAA, SPOT, NASA, ESA) recognize the need for continuity in satellite data and there is some assurance that future satellites (for example the Landsat, SPOT or ERS series) will allow for continuity of data. However, there will also be many new satellites (e.g. ODEOS, Radarsat) that will provide new and additional information. The list of existing environmental satellites is mentioned in Appendix 3. The satellite data are available from satellite companies, authorized distributors or national point of contact.

The cost of satellite data for global change purposes is currently under major review in several countries and there is a strong move (especially in the United States) to make data for such purposes available at reduced cost.

Satellite data processing includes the preprocessing phase -here the necessary radiometric and geometric corrections and the digital, visual or hybrid classifications of the imagery are made.

Future efforts

For future remote sensing efforts:

1. Consider limitations of sensors in development of classification systems, definitions of classes and reporting.

2. Request data in geo-corrected format. A significant proportion of remote sensing effort is getting data ready for processing. This should be done at regional centers (radiometric and geometric corrections and geo-coding and into a standard projection and data restructuring). Ground control points should be available in a file. There should be a catalog of ancillary data that could go along with the imagery data.

3. Collect data so it can be reformatted to FAO Forest Land Classification System.

4. Provide a common data set to allow more effective remote sensing calibration. Using well reported field data in combination with co-registered remote sensing data, different approaches and interpretation methods can be compared. These remote-sensing/field data sets should be available in public domain databases, held by FAO or UNEP, for instance.

3.4 Field Information

Successful international monitoring will have to utilize both remote sensing and field samples. This document provides both guidance for remote sensing activities and establishing field plots. We use remote sensing for large area mapping and monitoring. We use samples (both remote sensing and field) to:

a. Collect data not available from mapping/monitoring platforms and sensors (normally biomass, condition, productivity, ground vegetation, growth, etc.)

b. Provide a basis for research and model building.

c. Calibrate remote sensing (training, accuracy assessment)

Field information is an essential part in all forest inventory and mapping activities. Field information may be the only source or it can be combined with that obtainable by remote sensing. In some cases, the total area of interest can be surveyed in the field, but more often only field samples are measured.

The main categories of the use of field samples are as follows:

a. Forest inventory and monitoring
- as an independent field sample
- combined to remotely sensed data (training, accuracy assessment)

b. Forest research (growth and yield)

The type and sampling of field plots is usually optimized for the purpose. In case of combined use of field and remote sensing data also field plots not planned for this purpose may be of good value. Accordingly, also plots measured for growth and yield studies are, with some reservations, usable.

Field plot configuration

A plot is as a known location on the Earth's surface having defined boundaries or point of origin. The plots can be small or large, circular or square, rectangular or variable depending on the vegetation or forest type, on mensuration traditions, and on how one will use the data. The plots can form clusters or they can be independent.

The field plot can be temporary or permanent, depending on the need to repeat the measurements. Temporary plots are measured only once and the possibility to revisit the site in order to detect change is not deliberated.

A permanent plot is:

- established, monumented, and documented in such a manner so one can remeasure the exact area and same objects at a later time and

- for which there is an intent and plan for remeasurement.

Permanent sample locations in the field must be marked "hidden", so that they will not be treated in a different way from the environment. However, the markings should be clear enough that the location can be found and the measurements can be repeated after several years.

For most monitoring efforts it is convenient to use fixed-area plots. There is no question if a tree is ingrowth, ongrowth, in or out. Therefore, fixed-area plots are less subject to error. Often it is useful to record the location of each tree.

The size and layout of the plots depend much on the forest conditions like accessibility, vegetation type and size of the trees. However, the locating of field plots in remotely sensed data is easier if the field plot size is large enough. For this and reasons based on the efficiency of stratified sampling, for linking the field plots to remote sensing imagery, plots that are somewhat larger than the optimum size for pure field sampling are recommended.

To create the connection from satellite data to ground conditions, field data are always needed. If the goal is to follow-up the forest conditions, permanent plots with repeated measurements would be necessary. All the data collected during the field activities should be geo-referenced, for instance, by using UTM (Universal Transverse Mercator) or corresponding coordinates. Plots should be located on the forest maps in the traditional or digital forms.

If you wish to link the field plots to remote sensing imagery, then consider using:

a. Plots that are large enough to represent the existing biotope orenvironment. The larger the plot the easier it is to use as a reference for satellite data, supposing that the enlarging does not cause need for dividing the plot.

b. A cluster of small field plots spread out over an area that is at least equal to the area of a pixel.

For any project involving the establishment of permanent field plots,

- General description of how the sample locations are geo-referenced e.g., latitude and longitude or UTM.

- Plot type and size

- Exact time of field measurement

- Number of sample locations

should be provided.

The use of global positioning systems (GPS) can assist in determining the geographic coordinates and the use of geographic information systems (GIS) can assist in merging geo-referenced plot data with digital remote sensing.

3.5 Future Monitoring Efforts

For future efforts:

1. Collect and record minimum information called for in Chapter 2 and according to definitions and standards given in Appendix 1.

2. Use same standards, definitions, classification and bands on future monitoring or measurement efforts.

3. Be sensitive in reporting country statistics especially if the country in question did not help in the project. Countries should manage their own resources but should be aware they may be monitored by others. Institutions can monitor world forests, but are urged to report limitations and to advise countries being monitored.

4. Indicate if databases/imagery are available for others (nations/other international organizations) to use (see Appendix 5).

5. Provide list of contacts.

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4. SAMPLING DESIGN

For forest inventory and monitoring purposes, sampling design is of great importance. The purpose of sampling design is to ensure efficient data collection as measured with cost and reliability.

Start with clarifying the major needs for information and leave the design open for additional variables. Inventory and monitoring originate usually from local needs. Aggregation technique is especially true for global inventory and monitoring. The key issue here is to discuss the sampling design on local and national levels which should meet the integration requirements at global level.

Monitoring can be carried out using two basic methods; 1. Conducting studies at different times using independent samples, and expressing the change as the difference in the results. 2. Using the same sample locations at different times and deriving the change as differences of variables in sample units. Sampling with partial replacement is often to be considered although the application of the most advanced estimators may be difficult in the case of multi-purpose and successive inventories.

The advantage of the method of periodic measurements of sample locations is that it is efficient especially in measuring changes and the sampling errors are usually in the same direction and thus do not disturb strongly the change assessment.

The change assessment in the latter method is made by permanent plots, pixels or even larger areas to be called monitoring units. For example, areas to be repeatedly supplied by remote sensing scenes can be regarded as monitoring units.

The number of alternative sampling designs and corresponding estimators is high. For small area inventory and monitoring tasks pure field sampling, e.g. systematic cluster sampling, may be efficient. For larger area inventories combined inventory methodology with remote sensing becomes appealing. The reader wishing to know more about statistical principles is referred to Cochran (1963) and Frayer (1979) among many others.

4.1 Steps in Sample Design

After the information needs are known, define the population of interest. This should be done with concordance of the type of sampling unit. If the sample is taken with plots the population should be defined as the very large number of equidistantly placed plots. In case stands/compartments are used the population is the aggregate of all compartments within the area of interest.

In natural forests using sample plots is, from a theoretical point of view, more recommendable than using stand compartments as sample units. The borderlines between neighboring compartments cannot be defined unambiguously and they tend to be sensitive to subjectivity. For practical reasons, however, vegetationally homogeneous units, i.e. stand compartments or biotopes, are often attractive. This is especially true if the stands or other homogeneous units can be separated using remote sensing, or if a stand map would be available.

Next, check the existing information describing the population of interest. Satellite images, like NOAA, Landsat or Spot etc., aerial photographs, vegetation maps or forest management stand maps may provide a suitable basis for stratification. Old field data may give some tentative information - of change rate or forest variation - which can be utilized in sampling design.

Lastly, the decision about the inventory and monitoring design should be made with an acceptable size of the sampling error. Think of a set of alternative feasible designs and select the optimum one by taking cost-efficiency into account. Non sampling errors, especially potential bias related to measurements and models must be taken into account as well.

4.2 Stratification

Stratification is a powerful tool to improve the efficiency of forest inventory and monitoring and it should be always considered. Maps and remote sensing imageries can find their use through stratification. The idea is to put the areas or sample units which are similar to each other, in regard to map and image information, into the homogenous strata. What the strata really are, is usually studied by the field measurements. The less variation there is within a strata, the less field units are needed for the desirable accuracy.

The stratification techniques may differ from case to case. Here two kinds of stratification are considered: geographic stratification, i.e. area stratification and stratification of sampling units within sub-population.

Geographic stratification is made by maps. Remote sensing can be used as additional material. For example, a country and state, an ecofloristic zone, protected or reserved area, region near access roads can be addressed to different geographic strata. The intensity requirement for the inventory may differ from one geographic stratum to another. For example, mountainous areas beyond good access may be of less importance.

Each geographical stratum (sub-population) may be inventoried by an appropriate intensity and methodology. However, it may be important to calculate inventory results also for other sub-populations than the original geographic strata. In this case the inventory designs for different strata should not be too different. There are possibilities to gain necessary flexibility by weighting the field measurements in an appropriate way. Prestratification according to geographic areas should not restrict calculation of inventory results for any desirable sub-population (or stratification in later successive inventories).

Efficiency in estimating dynamics and trends in forests is increased when we use permanent plots and pre-stratify our sample so that sampling intensity is higher in strata or regions that have been regarded as most interesting and important. Again, flexibility should be maintained to change the strata in later inventories if desirable.

For the stratification within sub-population auxiliary or ancillary or pre-information is needed for each sample unit. The sample units will then be stratified into homogeneous strata by the use of the auxiliary data. There are often, but not always, good reasons to make this stratification independently for each sub-population.

A commonly applied stratification is to delineate the inventory area into homogenous stands or compartments and estimate each stand or compartment in the field by ocular classification or measurements. In the latter part it is assumed, however, that sample plots are used as the unit of design.

4.3 Multi-Stage and Multi-Phase Sampling

It is easy to get confused with the terms multi-stage and multi-phase sampling. In extensive forest inventories there may exist elements from both types of sampling. Typical to multi-stage sampling is that the sampling units vary according to the stage whereas the sampling units are the same throughout the phases in the multi-phase sampling. There may be great similarities in the use of different data sources. The techniques will be illustrated by the following data sources:

	Sampling unit	
Stage Material or Phase	**Multi-stage**	**Multi-phase**
1. Satellite imagery	sat. imagery scene	field cluster
2. Aerial photo cov.	aerial photo scene	field cluster
3. Field measurement	field cluster	field cluster

4.3.1 Multi-Stage Sampling

Multi-stage sampling techniques can be applied in many different ways. Let us assume that stratification is used. Satellite imageries are first stratified or listed in the order of importance in relation to the inventory. Some satellite imageries are then sampled for more detailed study by aerial photographs. Again, aerial photo scenes are stratified and some of them are sampled to be measured in the field. The stages are illustrated in more detail as follows.

Stage 1

a) Dividing the total area into satellite scene areas, N1.

b) Acquiring satellite imageries for all or a sample of N1. Assume n1 satellite imageries are acquired and stratified into strata described by index h ($\Sigma n1_h = n1$).

c) Dividing the n1 satellite scenes into N2 aerial photo scenes, i.e., second stage units.

d) Stratifying the N2 photo scenes through satellite imageries into strata ($\Sigma N2_h = N2$).

Stage 2

a) Drawing a sub-sample of n2 from all the N2 scenes for aerial photography.

b) Taking aerial photography for the n2 photo scenes.

c) Dividing the n2 photo scenes into N3 potential field cluster areas.

d) Stratifying the N3 field cluster areas by photo interpretation into strata ($\Sigma N3_h = N3$).

Stage 3

a) Drawing a sub-sample of n3 from the N3 field cluster areas.

b) Sampling each of the n3 field cluster areas with a cluster (systematic sampling often preferable).

c) Measuring all desirable variables for the n3 clusters.

d) Calculating ground truth data for each of the N3 field clusters.

The weight of a ground truth measurement for a unit U_{hij} (e.g., volume m^3/ha or proportion of forest land), when calculating the estimates for the population is the reciprocal of the product of sampling fractions: $N1_h/n1_h*N2_{hi}/n2_{hi}*N3_{hij}/n3_{hij}$.

4.3.2 Multi-Phase Sampling

Multi-phase sampling differs from the above design through the fact that the sampling units are the same in all levels. Two kinds of multi-phase sampling techniques are common in text books: multi-phase sampling for regression and for stratification. The latter is recommendable for multi-purpose forest inventories and the main features of it are described here. Referring to the earlier example, the sampling unit is a field cluster. The example gives us the following list of phases and activities.

Phase 1

a) Dividing the total area of population or sub-population into units of equal size representing a field cluster area. The number of units, say N1, becomes easily very high. The units are best defined by maps and coordinate systems.

b) Acquiring satellite imageries to cover all or a sample of N1. Assume n1 units are covered by the satellite imageries and taken for first phase sample.

c) Stratifying the n1 units into homogeneous strata through satellite imagery resulting in $n1_h$ units in a stratum h.

Phase 2

a) Drawing a sub-sample of n2 from n1 units resulting $n2_h$ units from stratum h.

b) Acquiring aerial photo coverage for the sub-sample of n2. For practical reasons, the sub-sample should be concentrated geographically into some kind of tracts in order to rationalize aerial photography, photo-interpretation and, especially, field measurements.

c) Interpretation of the n2 second-phase units from aerial photographs for variables which are in high correlation with those variables regarded as important for forest inventory and monitoring.

d) Stratifying the n2 units on the basis of photo interpretation resulting in $n2_{hi}$ units in a stratum hi.

Phase 3

a) Drawing a sample of a feasible number, $n3_{hi}$, of the units of each second phase stratum for field measurements. Again, it is important to consider the concentration of the n3 field units geographically into tracts to avoid high travelling costs.

b) Measuring all the variables which are regarded as important in forest inventory and monitoring in the field.

c) Calculating ground truth data, i.e. vector of desirable forest and land cover variables, for each field sample unit.

Illustration of the three phase sampling and estimation is presented in Appendix 4.

4.4 Purposive or Non-statistical Sampling

Sometimes, we may lack possibilities to gather field data in an objective way. Instead we may be able to make some measurements not too far from roads. Even these measurements are better than nothing in combination with map or satellite data. It is possible to try to find field information for every stratum by purposive sampling. Even plots measured for other purposes, growth and yield research plots, may be acceptable.

A method used frequently for forest classification from satellite imagery is supervised classification. Specific reference areas are selected for different kinds of image features. Each reference area will be defined in the field for a class. Reference areas belonging to the same image feature make a specific class. Then, by a specific algorithm, e.g. by maximum likelihood, all the image pixels are classified to the most probable area class with a given reliability requirement. Those pixels which do not find a reference area class go to the class "unclassified".

Locating reference areas for supervised classification does not always fulfil the statistical requirements and the technique can be classified as purposive or non-statistical sampling. The method, however, can be recommended if there are only few classes to which the total area should be divided or if there is a specific class to be mapped, e.g. damaged forests.

4.5 General Aspects

In principle, sound statistical procedures should be favored in designing forest inventory and management. Systematic sampling is more practical and efficient than random sampling and can be recommended. Model based sampling is gaining importance but is not widely applied yet.

All the information inside an inventory and monitoring area should be handled in the coordination and time system. This means theoretically that all information fulfills the requirements of a permanent plot from this point of view. The accuracy in location of all information is important to emphasize.

Plots measured in the field usually play an essential role. Effort should be directed towards getting a good representation of the whole population by field plots both geographically and in relation to strata inside a geographic stratum.

Permanent field plots are essential when monitoring changes, i.e. inventorying forest dynamics. For accurate location of permanent plots, global positioning systems should be considered. For monitoring growth and removal of trees, tree mapping is important. Using polar coordination, bearing and distance of trees from the centre point, is usable. Permanent plots can also afford usable data for growth and yield studies in addition to forest inventory and monitoring.

The final inventory and monitoring result is greatly dependent on the number, size, geographic and stratum-wise distribution, and the type and quality of measurements of field plots. Controlling data quality is always important. Crews should have good training and the quality of measurements should be checked objectively.

If developing a new program, sample design should be kept simple especially at the start. This makes quick and unambiguous results possible. More sophisticated and efficient systems are to be built upon as expertise, interest, support, and funding increase. This leads to exploring the use of remote sensing and plot configuration to match the appropriate technology.

If no stratification and remote sensing are available some kind of systematic sampling is sensible. The field plots should be distributed geographically as evenly as possible. At the same time, attention should be paid that the average travelling costs from one plot to another do not rise too high. This usually means a need for clustering the field plots.

In general, estimates made using rigorous scientific methods are more reliable and more believable to those who use inventory and monitoring data. It is better to have a few reliable plots than a lot of unreliable ones. Data will be used by scientists who understand statistical precision and use estimates of precision to interpret the reliability of their scientific results. Estimates of statistical precision can be used for analyzing policy alternatives.

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5. BUILDING AN INFRASTRUCTURE

5.1 Framework

A global data base should be based on a national level framework that can be aggregated to the global level. Major portions of this framework exists today in many regions of the world in both developing and developed nations. International institutions can help by monitoring regions that do not have the support for good monitoring at the national level. International monitoring efforts should have objectives that support and help building the country's own capacity to improve the national framework for forest monitoring.

Participating nations, organizations and scientists should:

1. Encourage and advise donor agency support especially for developing countries.

2. Encourage government and national institutional support.

3. Encourage the coordination and standardization of remote sensing forest research.

4. Recognize the need for better communication and coordination among scientists, nations and organizations and among donor agencies themselves.

5. Recognize the importance of currently existing forest data and suggest that a data bank be established by an international organization for search and retrieval of data (See for instance Appendix 5).

6. Encourage the establishment of new revenues for forestry research support.

5.2 Organization

FAO and UNEP may be the logical organizations to coordinate and carry out global resource monitoring activities. These organizations already have mandates to do this, and their capability must be strengthened. International organizations should communicate and coordinate with member nations and other organizations contributing to regional and global assessments.

Each country should have equal access to new technology and data. Training is necessary especially in developing nations. Special efforts should de made so that data flow in both direction - from international organizations to member countries - to scientists and decision-makers and vice versa. To make the information flow work, existing databases compiling global, regional and national forest data must be strengthened and new ones established.

5.3 Monitoring Plan

Those who want to conduct a monitoring effort should develop a monitoring plan with a strategy to implement it. This should include:

National and international organizations must be reminded of the need for financial and institutional support for forest monitoring. Some agencies to be contacted are found in Guide to Grants and Fellowships by USDA Forest Service.

1. *Authority* - The legal mandates or charters under which the organization will carry out the monitoring program.

2. *Policy* - The general guidance to the monitoring organization.

3. *Goals* - Develop goals through an information needs assessment (see Section 2).

4. *Responsibilities and Infrastructure* - Statement of who does what, when, and in what sequence.

5. *Definitions of Terms, References, and Sources of Information* - Develop common standards for gathering data and for aggregation of comparable results.

6. *Sample Design* - Include sample intensity, plot design and configuration that relates best to monitoring goals.

7. *Variables to Measure or Observe* - Include standards, definitions, and coding (See appendix 1).

8. *Field Instructions* - Include procedures for referencing and monumenting the plots and plot maintenance, measurement techniques, data recording processes, completing field forms, quality control measurements and schedule for plot establishment and remeasurement (see Appendix 1).

9. *Data Editing and Analysis Procedures* - How one will use the data to carry out the study goals, the statistical procedures one is to use, and reporting procedures.

10. *Plan for presentation of the results* - Printed research reports, maps, digital format, etc., including the accuracy assessment of the presented results.

11. *Budget Requirements and Funding Sources* for Establishment and Remeasurement.

12. *Signed Plan Approval* - A copy of the approved plan should be sent to the coordinating organization.

At the local level, public support and publicity for the monitoring effort would make implementation easier. Partnerships or alliances with concerned organizations and environmental groups are necessary. Striving for consensus and forming the partnerships with potential supporters and cooperators with common information needs may save funds and effort.

Do not forget the information directed to large audiences. Presentations could be in the form of simple but compelling photographs, videos, or popular literature. Establish pilot projects as demonstrations. A typical pilot project might be more easily sold to a funding agency. Consider the establishment of living or green libraries of trees within plots to educate the public.

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APPENDICES

APPENDIX 1 - STANDARDS AND DEFINITIONS

Use the following definitions and standards for collecting resource data to ensure the international usability.

General terms

Forest - An area with minimum 10 % tree crown coverage of trees of land surface in the tropics and 20 % crown coverage in temperate and boreal zones.

Tree - Woody perennial having generally one main stem and capable of reaching at least 7 meters at maturity.

Monitoring - The periodic measurement or observation of selected physical, chemical, and biological parameters for establishing baselines and for detecting and quantifying changes over time.

Plot - A known location on the Earth's surface having defined boundaries or point of origin.

Permanent plot - A plot that is established, monumented, and documented in such a manner so one can remeasure the exact area or same objects at a later time (Lund and Thomas 1989) and for which there is an intent and plan for remeasurement.

Plot location

Location coordinates - For global purposes, Latitude-longitude or Universal Transverse Mercator are recommended. If national coordination systems are used, conversion formulae to the global standards must be presented.

Elevation - The altitude above mean sea level that the center of the plot occurs. Record in meters.

Slope - The slope in degrees or percentages (45 degrees=100%) within the plot or the defined land area.

Aspect - The direction a slope of land faces. Record to the nearest degree.

Terrain position - The elevation of the plot compared to the neighboring area - higher, lower or average refer to peak, depression or middle slope, respectively.

Area Classification

Area condition radius - The radius in meters surrounding the plot for which the general plot characteristics apply.

Land use class - The predominant purpose for which an area is employed such as agricultural land, forest land, range land, wetland, urban, transportation and utility corridors. (see appendix 2).

Land cover class - That which overlays or currently covers the ground, especially vegetation, permanent snow and ice fields, water bodies, or structures. Barren land is also considered a "land cover" although technically it is lack of cover. The term land cover can be thought of as applying to the setting in which one or more types of land use (or actions) take place. (see appendix 2).

Crown closure -Percentage of the ground covered by a vertical projection of the outermost perimeter of the natural spread of the foliage of plants.

Stand History - 1. The kind of disturbance (prior to plot establishment) on the sample location. Use past records or visually determine on the plot. 2. - The number of years when the most recent disturbance took place.

Tree/plant ratings

Plant Species - The major subdivision of a genus or subgenus of a plant being described or measured. Determined from training, by use of key, or by a botanist.

Diameter at Breast Height (DBH) - Normally the outside bark diameter at 1.30 meters above the ground level. 4 feet 6 inches in U.S. On slope, ground level is measured from the up hill side of the tree. Sometimes respective girth at breast height (GBH) is used.

Tree height - The total span of a tree from the ground level to the tip of the tree.

Age - The total age of a tree.

Growth - The difference between the values of a variable at the end and at the beginning of the measuring period.

Stem ratings

Log size - Diameter (most often top diameter) and length of the merchantable portion of a tree.

Timber quality - Quality class of the timber.

Crown ratings

Crown diameter - The span of the crown of a tree or shrub. Measured as the diameter of the vertical projection of the outermost perimeter of the crown in certain direction.

Crown length - The vertical distance from the top of the leader to the base of the crown, measured to the lowest live branch-whorl with live branches, and continuous with the main crown.

Leaf area - The total area of leaf surfaces.

Defoliation - The visual index of actual foliage compared to the normal, healthy tree growing in similar conditions. Measured as percentage of the 'normal' foliage.

Bioindicators - A characteristic of the environment that, when measured, quantifies the magnitude of stress, habitat characteristics, degree of exposure to the stressor, or degree of ecological response to the exposure (Hunsaker and Carpenter 1990). For instance, existence of certain lichens have been used as bioindicators.

Damage - Evidence of mechanical or biological damage to a tree or plant such as insect, disease, fire, wind.

Dendrochronology - The relation of tree rings to past growing conditions.

Understory vegetation - Description of the vegetation under certain height, ie. 50 % of the dominant height of the trees.

Foliar chemistry - Content of key elements such as K, Ca, N, Mg, SO3, etc.

Soil indicators - Includes nutrients, soil texture, compaction, chemistry, etc.

APPENDIX 2 - FAO LAND COVER/USE CLASSIFICATION

November 1993

Note: UNEP and FAO are in the process of revising land cover and land use schemes for global monitoring. The following is the FAO classification system currently being used. Those wishing to be consistent with the latest system should check with UNEP and FAO first.

Land cover/use class

A. Tropics. The main categories of land in the Tropics are Forest (crown cover >10%) and Nonforest. Forest and Nonforest are further divided as follows:

Forest

1. Closed forests are vegetation formations where trees occur in single or multiple stories with crowns interlocking, which, in conjunction with the undergrowth, cover a high proportion (> 70 %) of the ground and consequently do not have a continuous dense grass layer at the ground level. They are either managed or unmanaged forests, primary or in advanced state of succession and may have been logged-over one or more times, having kept their characteristics of forest stands, possibly with modified structure or composition.

After predominance in cover by species closed forests are further distinguished into three types:

- **1.1** Broadleaved forests
- **1.2** Coniferous forests
- **1.3** Bamboos/Palms formations

2. Open forests are vegetation formations where trees occur with discontinuous, non-interlocking crowns, but with a crown coverage of at least 10 %. Generally there is a continuous grass layer allowing grazing and spreading of fires. Examples are various from 'cerrado' and 'chaco' in Latin America, tree and wooded savannas, and wooded lands in Africa, dry dipterocarps forests and 'forets claires' in Asia.

Open forests are distinguished into

- **2.1** Broadleaved and
- **2.2** Coniferous

The basis for further subdivision of forests are forest origin (natural/plantation), forest function (conservation/protection/production), forest land ownership (public/private) and legal status of forest land (legally constituted/other forest land).

Nonforest contains the following land use class:

1.Wooded land

- **1.1** Forest fallow refers to all complexes of woody vegetation deriving from the clearing of natural forest for shifting agriculture. It is an intermediate class between forest and nonforest land uses, consisting of a mosaic of various succession phases and includes patches of uncleared forests and agriculture fields.

1.2 Shrubs refer to vegetation types where the dominant woody elements are shrubs with 0.5-5 m height on maturity.

2. Other land uses

2.1 Arable land refers to land under temporary crops, temporary meadows for mowing or pasture, land under market and kitchen gardens, and land temporarily fallow or idle.

2.2 Land under permanent crops is cultivated with crops that occupy the land for a long period and need not be replanted after each harvest.

2.3 Permanent meadows and pastures are used permanently (5 years or more) for herbaceous forage crops either cultivated or growing wild.

B. Temperate and Boreal. In temperate and boreal zones, the definition of forest is also based upon canopy cover (> 20 %) although national systems may be based upon the capability of the lands to produce roundwood and the legal status. The nonforested areas are either unproductive (mountains, tundra, or desert) or occupied by agriculture, settlements or other land uses

APPENDIX 3 - REMOTE SENSING CHARACTERISTICS

The following tables are summaries of remote sensing capabilities and uses from Prince et. al. (1990) and other sources.

Table 1. Remote Sensing Characteristics (Prince et. al. 1990)

Satellite	Launch	Ended	Local Time	Repeat Orbit	Alt. (km)	Incl.(°)	Swath Width
Landsat 1	23-07-72	16-1-78	8:50	18 days	900	99	185 km
Landsat 2	22-01-75	25-02-82	9:08	18 days	900	99	185 km
Landsat 3	05-03-78	31-3-83	9:31	18 days	900	99	185 km
Landsat 4	16-07-82		9:45	16 days	705	98.2	185 km
Landsat 5	01-03-84		9:45	16 days	705	98.2	185 km
SPOT 1	21-02-86		10:30	26 days	832	98.7	117 km
SPOT 2	21-01-90		10:30	26 days	832	98.7	117 km
NOAA 7	23-06-81	07-06-86		9 days	833	98.9	2700 km
NOAA 9	12-12-84	operat'l					2700 km
NOAA 11	24-09-88	operat'l					2700 km
NOAA 6	27-06-79	02-04-87					2700 km
NOAA 8	28-03-83	01-01-86					2700 km
NOAA 10	17-09-86	operat'l		18 days			2700 km
Seasat	06-78	01-10-78		17 days	908.7		
MOS-1 MESSR	06-86		10:30			99.1	100 km
MOS-1 VTIR							1500 km
MOS-1 MSR							317 km
Meteosat 1	23-11-77	84	(a)				
Meteosat 2	19-06-81	88					
Meteosat 3	19-06-88	(b)					
Meteosat 4	06-03-89	operat'l		na	158		
DMSP F8	19-06-87	operat'l		na	152/172	98.7	833 km
MOMS STS-7	18-06-83	18-07-83	na	6 days	780	28.5	138 km(c)
MOMS STS-11	03-02-84	03-06-84	na			28.5	138 km(c)
NIMBUS-7	24-10-78	08-87	noon			99.28	

(a) geostationary.
(b) standby.
(c) at 300 km altitude.

Table 2. Satellite Sensor Description.

Satellite	Sensors	Mission	Channel Band #	Spectrum λ (v)	Resolution (m)	Bits
Landsat	RBV	1,2	1	0.275-0.575 µm	80	
			2	0.580-0.680 µm	80	
			3	0.698-0.830 µm	80	
		3		0.505-0.750 µm	30	
	MSS	1-5	1(4)	0.5-0.6 µm	79/82	128
			2(5)	0.6-0.7 µm	79/82	128
			3(6)	0.7-0.8 µm	79/82	128
			4(7)	0.8-1.1 µm	79/82	128 (a)
		3	5	10.4-12.6 µm	240	128
	TM	4,5	1	0.45-0.52 µm	30	256
			2	0.52-0.60 µm	30	256
			3	0.63-0.69 µm	30	256
			4	0.76-0.90 µm	30	256
			5	1.55-1.75 µm	30	256
			6	10.40-12.5 µm	120	256
			7	2.08-2.35 µm	30	256
SPOT	HRV (XS) (b)	1,2	1	0.50-0.59 µm	20	256
			2	0.61-0.68 µm	20	256
			3	0.79-0.89 µm	20	256
	HRV (P) (b)			0.51-0.73 µm	10	256
NOAA	AVHRR (1)	6,8,10	1	0.58-0.68 µm	1.1/4 km	1024
		(A,E,G)	2	0.72-1.10 µm	1.1/4 km	1024
			3	3.55-3.93 µm		1024
			4	10.5-11.5 µm		1024
			5	10.5-11.5 µm		1024
	AVHRR (2)	7,9,11	1	0.58-0.68 µm	1.1/4 km	1024
		(C,F,H)	2	0.72-1.10 µm	1.1/4 km	1024
			3	3.55-3.93 µm		1024
			4	10.5-11.5 µm		1024
			5	11.5-12.5 µm		1024

(a) 64 on Landsat 1 and 2 MSS band 4(7).
(b) (XS) multispectral mode, (P) panchromatic mode.

(table continues on the next page)

Table 2. b Satellite Sensor Description Continued

Satellite	Sensors	Mission	Channel Band #	Spectrum λ(v)	Resolution (m)	Bits
MOS	MESSR	1	1	0.51-0.59 μm	50	64
			2	0.61-0.69 μm	50	64
			3	0.72-0.80 μm	50	64
			4	0.80-1.10 μm	50	64
	VTIR		1	0.5-0.7 μm	0.9 km	256
			2	6.0-7.0 μm	2.7 km	256
			3	10.5-11.5 μm	2.7 km	256
			4	11.5-12.5 μm	2.7 km	256
	MSR		horiz.	23.8 GHz	32 km	1024
			vertical	31.4 GHz	23 km	1024
Meteosat	VIS	1,5		0.5-0.9	2.5 km	256
	IR			10.5-12.5	5 km	256
	WV (c)			5.7-7.1 m	5 km	
Nimbus/Seasat	SMMR	7/A	h or v	6.6 GHz	151/97 km (d)	256
			h or v	10.7 GHz	91/59 km	256
			h or v	18 GHz	55/41 km	256
			h or v	21 GHz	46/30 km	256
			h and v	37 GHz	27/18 km	256
					h/v/h/v (e)	
DMSP	SSM/I		hor/vert	19.35 GHz	69/43/69/43	
			vert	22.23 GHz	/-/50/-/40	
			hor/vert	37.0 GHz	37/29/37/28	
			hor/vert	85.5 GHz	15/13/15/13	
Seasat	SAR		L band	23.5 cm	25 m	
Space Shuttle	SIR - A		L band	1.28 GHz	38 m	
	SIR - B		L band	1.28 GHz	58-17 m	
	MOMS	STS7/	1	0.575-0.625 m	20 m	
		STS-11	2	0.825-0.975 m	20 m	

(c) water vapor band could not be operated simultaneously with other two bands.
(d) 151/97 = resolution for major/minor axis of polarization respectively.
(e) 69/43/69/43 = resolution (in km) for horizontal along-track/vertical along-track/horizontal across-track/vertical across-track respectively.

Table 3. Characteristics, basic costs, and interpretation requirements for commonly used airborne remotely sensed types. The products presented are typical data formats that have been used for creation of GIS databases.

Data Sources / Characteristics	NAPP 1:40000	Resource Photography 1:24000	Resource Photography 1:12000	VIDEO
Spatial Resolution	NA	NA	NA	NA
Spectral Range	0.4-0.9	0.4-0.9	0.4-0.9	0.4-0.9
Type of composites possible	color/BW color-IR	color/BW color-IR	color/BW color-IR	color color-IR
Area of Coverage (per scene/photo)	9.1 km X 9.1 km	5.5 km X 5.5 km	2.6 km X 2.6 km	variable
Available as digital (Without additional processing)	NO	NO	NO	NO
Cost of scene as digital	NA	NA	NA	NA
Cost per 7.5' quad for digital or number of photos	10 photos	20 photos	71 photos	NA
Cost of hard copy per scene/photo	$ 8.00	$ 4.00 - 8.00 (Color/IR)	$ 4.00 - 8.00 (Color/IR)	NA
Frequency of coverage	5 years	variable	variable	variable
Typical hardware for interpretation	stereoscope & light table	stereoscope & light table	stereoscope & light table	VCR & computer software hardware
Digitizing Required	YES	YES	YES	NO

APPENDIX 4 - ILLUSTRATION OF THE THREE PHASE SAMPLING AND ESTIMATION

Notations:

U_{hij} = Third phase sampling unit j measured in the field and belonging to Stratum hi.
y_{hij} = A vector of stand variables for U_{hij} based on field measurements.
w_{hi} = Area proportion of Stratum hi.
n1 = The number of first phase sampling units.
$n3_{hi}$ = The number of third phase sampling units belonging to a specific Stratum hi.
U_{hr} = Any first phase sampling unit belonging to Stratum h.
y_{hr} = The estimate of stand variables for U_{hr}.

The estimate y_{hr} can be derived from the field measurements y_{hij} which belong to stratum h. The weight of a corresponding third phase sample unit U_{hij}, p_{hij}, is $w_{hi}/\Sigma w_{hi}/n3_{hi}$.

The given algorithm is flexible for calculating estimates for any given sub-population. The estimates can be calculated irrespective of whether there are third or second phase units among the first phase units belonging to the sub-population.

Every stand variable vector measured in the field, y_{hij}, is used according to its weight, p_{hij}. Assume, y_{hij} has been measured per unit area, e.g. volume m^3/ha. The estimate for a total of the sub-population, T, can be estimated by:

$$T = \sum_h n1_h A1_h \sum_i \sum_j p_{hij} y_{hij} \text{ , where}$$

$$A1_h = \text{The area cover represented by } U_{hr}$$

Take an arbitrary unit U_{hr} belonging to the first phase sample. The location of the unit is defined in a map or UTM coordination. The idea on finding relevant estimates for this arbitrary unit is to go the route downwards to the field measurements made under the Stratum h and to weight each variable vector y_{hij} with p_{hij}.

Once the estimates are derived for each first phase unit it is fairly simple to calculate the first order results, e.g. mean values and distributions for any given sub-population. This procedure has been functioning well in the national forest inventory of northern Finland when two phase sampling has been applied (Poso and Kujala 1978).

APPENDIX 5

IUFRO S4.02 - 05 QUESTIONNAIRE ON PERMANENT PLOT NETWORKS

****

The purpose of this questionnaire is to collect information on permanent plots and the characteristics of permanent plot networks and incorporate the information into a data base The data base will be used to determine the scope and application of permanent plot networks. The report will be made available by request to those who are interested in the results. This data base is maintained and updated by UNEP GEMS PAC. However, UNEP holds no responsibility for the content and the accuracy of the data set held in the archive. Send the completed questionnaire or data requests to IUFRO Permanent Plot Database Manager, GEMS PAC, UNEP, P.O. Box 30552, Nairobi, Kenya. Tel: +254-2-621234. Fax: +254-2-226491 or 226890. E-mail: myint@un.org at Internet.

****

PLEASE FILL OUT ONE FORM PER DISTINCTIVE PLOT NETWORK TYPE

Organization ________________________________

Contact Person ____________________ Title ______________

Street Address ______________________________

____

City ____________ State or Country ________________

Zip Code ______________ Country Code ______________

Telephone Number (with country code) ________________

Fax Number (with country code) ________________

1. Do you have permanent sample plots (circle one choice):

   A. YES B. NO C. Under Consideration

2. Are plots for regional/national inventory (circle one choice):

   A. YES B. N0

IF YOU DO NOT COLLECT DATA ON PERMANENT PLOTS, PLEASE STOP HERE.

****

3. Number of plots: ______________________________

4. Year established (If over several years, record earliest year): ______________________________

5. Year last measured (If over several years, record latest year): ______________________________

6. Are plots geo-referenced by a coordinate system (choose one):
   1. Fully
   2. Partially
   3. Not at all

7. Area covered by plot network (in km^2): ____________________

8. Vegetation types (circle all that apply):
   1. Coniferous vegetation
   2. Broadleaf forest
   3. Mixed forest
   4. Bamboo/grass
   5. Peatland
   6. Other, specify ______________________________

9. Shape of plot (circle one):
   1. Fixed rectangle
   2. Fixed circular
   3. Variable (relascope etc.)
   4. Mixed
   5. Linear
   6. Other, specify ______________________________

10. Size of plot (circle one):

1. 0.01 ha or less	(0.025 acres or less)
2. 0.011 ha - 0.05 ha	(0.026 acres to 0.12 acres)
3. 0.051 ha - 0.1 ha	(0.13 acres to 0.25 acres)
4. 0.11 ha - 1.0 ha	(0.251 acres to 2.5 acres)
5. 1.1 ha - 10 ha	(2.51 acres to 25 acres)
6. 10.1 ha or greater	(25 acres or greater)
7. Other, specify______________________________	

11. Any remote sensing data (circle one):
    A. YES B. NO

12. If yes, what type (circle one):
    A. Satellite B. Aerial photos

13. Most frequently used scale of photography (circle one):
    1. 1:999 or less
    2. 1:1000 - 1:4999
    3. 1:5000 - 1:9999
    4. 1:10000 - 1:19999
    5. 1:20000 - 1:29999
    6. 1:30000 or greater

14. Latest year remote sensing data was collected: ______________

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The main sponsor of this effort has been the Finnish International Development Agency FinnIDA. Other organizations contributing to the development work include: the University of Joensuu and University of Helsinki, Finland, Kasetsart University, Thailand, the European Forest Institute (EFI), Finland, and the United States Department of Agriculture (USDA) Forest Service Tropical Forestry Program.

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ISBN 3-901347-00-3