NEW THRUSTS IN FOREST INVENTORY

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Risto Päivinen, Jerry Vanclay and Saija Miina (eds.)

EFI Proceedings No. 7, 1996

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NEW THRUSTS

IN FOREST INVENTORY

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The papers in this book comprise the proceedings of the subject groupmeetings mentioned on the cover and title page. They reflect the authors' opinions and do not necessarily correspond to those of the European Forest Institute. The papers are published as presented in the interest of timely dissemination.

Cover: Archives of Newspaper Karjalainen / Mika Parkkonen
Jari Saksa and Kari Soininen collecting data for the Finnish National Forest Inventory.

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FOREWORD

The IUFRO subject groups 4.02 'Forest Resource Inventory and Monitoring' and 4.12 'Remote Sensing Technology' held ten separate or joint meetings during the IUFRO XX World Congress in Tampere, Finland, in August 1996. A total of 42 papers were presented at these meetings. The papers are published in two volumes of proceedings, namely, the one at hand and the other one published by the University of Joensuu.

As the new millenium is just around the corner, there are new expectations for forest inventory and remote sensing. These proceedings provide an overview of the current situation in these fields, as well as address some of the future challenges the research is facing.

I would like to thank all authors who have contributed to these proceedings. I would especially like to express my sincere thanks to Jerry Vanclay and CIFOR for their collaboration in publishing these proceedings.

Risto Päivinen
Incoming leader, IUFRO S4.02

New Thrusts in Forest Inventory

Moderator: G. Preto, Italy

INFORMATION AND INFORMATION TECHNOLOGY — A PROPOSAL TO BRIDGE THE INFORMATION GAP IN FORESTRY

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Abstract

The paper presents an overview over the current problems in forestry information and knowledge exchange. Reasons for the information poverty in forestry are listed and discussed. Based on a survey among international information users and providers requirements for efficient networks adjusted to local needs are developed to bridge the existing information gap. Finally, opportunities and constraints of emerging and rapidly growing information technologies such as CD-ROM and Internet are discussed with regard to different technical standards in various geographic regions.

Key words: Information technology, global network, Internet

Introduction

Humans are about to enter a new era that has often been referred to as information age. Information will play a critical role in commerce and science. Information will gain so much value that it will be bartered, bought and sold (Myers 1994).

Information and information technology — Determination of the terms

Information is knowledge applied for a particular purpose (Speidel 1984). Whenever the degree of uncertainty on a particular issue decreases one deals with information. The level of information used is determined by the ratio between costs and benefits of information. As long as the benefit exceeds the costs it makes sense to collect further information on a special task. The optimum level of information is the point of intersection between costs and benefits. This point is not fixed but subject to change. A tool to help approach this optimum is information technology. Information technology is defined as a method to provide the resource information. It is a resource for the resource information, also called meta-information.

Information and information technology in forestry

Forestry, especially in a global context, is characterized by a gap between knowledge and information as a result of poorly developed information technology. It seems that the amount of knowledge increases much faster than the means to exchange information, thus increasing the gap. This situation presents several problems.

Information such as project description and results, international trade figures and the likes are often stored but not accessible or available to those who need them. Those in need of scientific data or information have difficulty in locating the source of such information, let alone acquiring it. This failure to acquire relevant information such as research results leads directly to inferior forestry research and programs. Information as simple as species growth rates, pest and disease control, and genetic improvement techniques is well documented yet unavailable to many.

Second, there are both duplications of stored information and dramatic gaps of available information. This duplication and absence of information is carried over to research and field applications resulting in a less than optimum use of resources: financial, human and natural. Consequently, advances of science itself are slowed considerably as forestry institutions seldom are knowledgeable of activities among themselves and pursue individual interests, often unaware of similar, or identical activities elsewhere. The problems mentioned above are a result of what has been termed "information poverty". Even cases in which information has been duplicated can fall under this category as an optimum use of resources has not been achieved. To effectively address and correct this information poverty several root problems must be rectified. These problems include, but are not limited to:

- There is little conformity in data input and extraction methodology between information sources, hindering attempts to coordinate or network two or more sources.
- Existing information systems and sources are not marketed and therefore not well-known or used to the extent they should be.

- If information is stored on highly sophisticated computers it is often too expensive or even impossible to many to access relevant information.
- Existing forestry information retrieval systems were often created on an ad hoc basis in response to a given need (Peck 1995). Such systems are re-active instead of proactive and can therefore be expected to be one step behind future needs in forest resource management.

The continued, and accelerated, growth of scattered forestry information sources combined with advances in computer and information technology emphasizes the need to develop a coordinated international forestry information network. Such a system must facilitate the two-way flow of scientific and technical information between information providers and users, be they international institutions, individuals, or local organizations. It is not perceived that this network would necessarily be another database, but more importantly a means of facilitating the coordination and use of existing databases and information sources. Information available within such an international network should include statistical and subject-based databases as well as expert and institutional contacts.

Current information use in forestry — a survey

Lately, the World Forest Institute conducted a survey to determine the state of forestry information among the individuals and institutions provided with information by the institute. The survey examined several facets of the information market, including:

- the principal information sources used
- main means to send information
- the preferred formats, such as newsletters, databases, or reports that are most successfully used to gather and disseminate information
- the attitude towards computer networks

The study should help to identify forest information challenges, focusing on the accessibility of information and how information exchange could become more flexible in the future.

The results include various types of organizations in seven different countries (USA, Canada, Brazil, Indonesia, Germany, Mexico, China) e.g. universities, research institutes, NGOs as well as governmental organizations.

More than 70% use a computer every day and only 4% never. However, the use of computers means for most people word processing. Less than 33% use their computer as a tool to gather information from online databases or the Internet. Print media, such as journals, books and newsletters account still for 90% of the participants as the main source of information.

The strides in technologies to send information lead to an increased share of faxes at the expense of traditional mail. Only 8%, however, use their computer as a main mean to send information.

When asked for their feelings about computer networks the participants had overall a very positive connotation of the term. "Helpful", "future", "scientists" and "forestry" were strongly associated with the term "computer networks". This brings up a few important questions:

- If 80% of the participants think computer networks are helpful, why don't they use them more?
- Why do 40% think computer networks and developing countries fit well, even though the infrastructure of telecommunication and power lines is poorly developed in most of these countries?

Or, to put it in a single question:

- Where does the gap between the feelings about computer networks on one hand and the actual use on the other hand come from?

The results of the survey cannot reveal the answers to these important questions. However, it has to be asked what this means for the distribution of information. Does it mean, for example, that we are only in a transition towards the widespread use of computer networks and the Internet as an information source? Or does it mean that many people have so positive connotations because they do not know enough about it?

There can be no final conclusion at this point. Nevertheless all organizations in forestry dedicated to information and knowledge exchange have to address these issues in order to determine their future emphasis on one or another mean of information exchange.

Information age and Internet — Emerging opportunities to bridge the information gap?

During the last decade great strides in information technology have taken place. Examples include the fast development in the performance of computer chips and CD-ROM, but even more important the rapidly growing Internet with its various services.

This is particularly remarkable because the Internet meets many of the demands for a functioning network. It forms a worldwide seamless network for its collective users and allows a two-way flow between information providers and users. Such a promising combination has been unique so far and yet the opportunities to come are hard to predict. Already it offers outstanding possibilities for the accessibility, adaptability, consistency and user friendliness of the information stored. In particular the World Wide Web, developed in 1991 in Switzerland, is a powerful tool which offers fast and inexpensive access to information that has been stored so far in many different databases not available for most information users (Schau et al. 1994).

Examples for powerful applications of the services of the Internet are library access, electronic publishing or fast and efficient information exchange via electronic mail.

Many forestry libraries are now universally accessible. This offers outstanding possibilities for researchers to gather information not available so far. Though most of these documents cannot be obtained full-text at the moment, efforts are underway to provide full-text access to many of these documents. In other fields than forestry the development is already further advanced. In molecular biology, for example, the European Molecular Biology Network has been established on the World Wide Web. It offers huge databases on the Internet. Most of these data was sitting on shelves so far. An advantage of publishing scientific journals electronically is that the time-lag between submitting a paper and its publication can be shortened substantially.

These are briefly some of the opportunities offered by modern means of communication. However, one has to be careful that the current enthusiasm about these technologies not further disenfranchises less developed societies. The world-wide use of Internet is still hampered by different technical standards. Besides, it has to be clarified if information users really rely on the Internet, though the increasing number of users is promising. For a successful forestry information and knowledge exchange it is crucial that a consistent approach to organize and provide data can be established. This could be done by an "information only" institution filtering the information provided in a network and setting up a special interest network for forestry. However, the international forestry community also has to unleash all efforts to avoid that the unequal accessibility to information sources is further exacerbated. Therefore various information technologies for different countries have to be applied until the disparity of information access has been overcome.

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INTEGRATION OF CANADA'S FOREST INVENTORY WITH THE NATIONAL ECOLOGICAL FRAMEWORK FOR STATE OF SUSTAINABILITY REPORTING

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Abstract

Canada has completed recently an initiative under the auspices of the Canadian Council of Forest Ministers that developed criteria and indicators for reporting progress on sustainable forest management. This state of environmental reporting of Canada's forest lands is not easy. Canada is ecologically diverse; there are many jurisdictions; certain data are lacking; current forest inventories do not allow for trend analysis; inventories are timber oriented; and often there is no consensus among stakeholders as to what constitutes a healthy forest or a sustainable forestry practice.

Two national initiatives facilitate this need for national level reporting on sustainability - Canada's Forest Inventory and the national ecological framework. This paper discusses the development and use of Canada's national ecological classification as a framework for reporting on the state of the country's environment. Focus is placed then on the Forest Inventory and its role in providing national forestry data from disparate provincial inventories. The benefits of a major cooperative initiative among forest agencies and Environment Canada in integrating the national forest inventory database with the ecological framework are discussed.

Key words: Inventory, ecological framework, forest health

Introduction

The state of environmental reporting on Canada's forest lands is not easy. Canada is ecologically diverse; there are many jurisdictions; certain data are lacking; data types often are not well integrated, current forest inventories do not allow for trend analysis; inventories are timber production-oriented; and often there is not consensus among stakeholders as to what constitutes a healthy forest or a sustainable forestry practice. Yet, the pressures on Canada's forest sector to measure progress towards sustainable forest management are increasing.

To address this need, Canada has recently completed an initiative under the auspices of the Canadian Council of Forest Ministers that developed criteria and indicators of sustainable forest management. The task falls on provincial and territorial forest agencies to collect and compile appropriate data to address these indicators, particularly the environmental ones, and to track them over time. Federal counterparts, in cooperation with these organizations, will be providing national overviews and trends on the sustainability of the country's forest ecosystems.

The development of criteria and indicators of sustainable forest management is an important step in informing the public on progress towards sustainability, but not sufficient in itself. There exists, as well, a need to set an ecological context for these indicators and to provide a reporting framework that puts forest ecosystems, and activities within these ecosystems, in the broader ecological picture. Also, this reporting must be understandable and relevant to both decision-makers and the public at large.

A recent major cooperative initiative between the Canadian Forest Service (CFS) and Environment Canada goes a long way towards linking the data needed for operational forest management with those which report on status and trends of the health of major Canadian ecosystems. This paper focusses on this initiative with discussion on both the national ecological framework and Canada's Forestry Inventory (CanFI) as well as their integration. The concepts and methodologies are discussed along with examples of application to state of sustainability reporting.

Setting the scene

There are 416 million hectares of forest land in Canada of which 245 million hectares are considered capable of producing commercial timber products (Lowe 1994). Of this, approximately 119 million hectares are currently suitable and available for timber production. Provincial governments are responsible for managing 71% of the nation's forests, and the federal and territorial governments oversee 23%.

While only 6% of Canada's forests are on private property, they belong to more than 425 000 landowners. The proportion varies from region to region. In Nova Scotia, for example, 69% of forest land is privately owned.

The economic importance of Canada's forests is enormous. Total value of shipments of Canadian wood and paper products was $44.2 billion in 1992. The industry continues to be Canada's largest contributor to foreign exchange earnings, exporting $26.7 billion of forest products. The net contribution to Canada's balance of payments is about the same as the aggregate of all mineral fuels, ores, chemicals, metals and agricultural products.

Direct employment in the Sector in 1993 was 311 000 workers, an increase of 22 000 from 1992. In all, 847 000 Canadians, 8% of the national workforce, earn their livelihood directly or indirectly through the forest sector. Three hundred and thirty-seven communities across the country rely primarily on the wood products industry for their economic and social well-being (Natural Resources Canada 1995).

Non-timber forest values from activities such as hunting, trapping, fishing, tourism and other recreational pursuits are significant as well. British Columbia recently completed a major Forest, Range and Recreation Resource Analysis for the province (British Columbia Ministry of Forests 1995). In this analysis the gross domestic product (1993) from the forest sector was approximately $7 billion. Gross economic value from all aspects of recreation was estimated as $3 billion. although not directly comparable to Canada as a whole, this analysis serves to illustrate the overall importance of our forest lands.

Not to be forgotten are ecological, cultural and spiritual values of the forest. Conservation of biodiversity and forest structure and function are paramount concerns. The continuing conflicts over the management of old-growth forests, from the temperate rainforest of Canada's west coast to the white and red pine stands of Ontario, vividly illustrate the public interest in these issues. Finally, the Canadian people in general, and the First Nations in particular, have a close historical, cultural and spiritual connection with the forests which are at least as important as the economic values.

For this mix of cultural,environmental and economic reasons, the conservation and sustainable management of forests is a clear priority of Canada's provincial, territorial and federal governments. Forest managers are committed to maintaining forests in a healthy state for the socioeconomic and environmental well-being of Canadians, as well as a contribution to maintaining global environmental quality.

Sustainable forest management

Is this priority reflected in results? Is Canada making progress towards sustainability? Are the forests healthier? Canadians want to know status and trends on these questions. To do this, not only is there a need to monitor and assess appropriate indicators but to do so in an understandable manner to a non-forestry community. Scientific research, monitoring and assessment have to be translated in terms of public values. Hydrological cycles, nutrient cycles, forest function and process must be reported in simple terms such as old growth, habitat loss, protected areas, endangered species, etc. State of sustainability reporting aims to bridge this gap from science and operational management to public communication.

An essential step in this reporting is to define the concept of sustainable forest management. In Canada, the following principles outline this concept (CCFM 1995):

- managing forests as ecosystems
- integrating environmental benefits and values, socioeconomic and cultural benefits, and institutional arrangements to formulate and implement appropriate policies and programs to monitor their effectiveness.
- minimizing impairment and avoiding unacceptable disturbance to forest ecosystems as a result of human activity within forests (eg. inappropriate harvesting practices) and outside forests (eg. airborne pollutants).
- involving Canadians in determining how their forests are used.
- criteria and indicators that characterize sustainable forest management should be based on the best available scientific knowledge and should meet international acceptance.

National reporting

It makes sense if one manages forests as ecosystems, that an ecological framework must coexist with current administrative frameworks. This framework should be hierarchical and nested to allow linkages between regional and national perspectives. If the public is to be involved public values must be incorporated. Communication must take place in the language of an informed public and not in the jargon of the scientist. Also, national comparability is essential. Flexibility to meet regional needs and conditions have to be reconciled with the needs of national reporting as much as is possible. Internationally, Canada's progress towards sustainability is viewed by others in its totality and not by its various regions. Unsustainable forest practices within a region of Canada reflect on Canada as a whole. National environmental sustainability reporting puts regional issues in perspective and provides a consolidated picture of Canada.

The provinces and territories, in cooperation with their federal counterparts, contribute to Canada's Forest Inventory (CanFI) to facilitate reporting on the country's forest lands at the national level. This database contains the best available information on Canada's forest lands. Being timber-oriented the data have many caveats, but they are underutilized in terms of interpretive value beyond understanding the forests and their use. Timber inventories across Canada are changing, becoming more holistic resource inventories. More information, on a regular basis, is being compiled on non-timber vegetation, wildlife, soils, visual site conditions and many other attributes. Undoubtedly, this "new breed" of forest inventory will continue to evolve to a true forest ecosystem inventory.

The national ecological framework

The concept

In order to embrace an ecological approach to resource management we must think, plan and act in terms of ecosystems. There is a need to move away from reductionist thinking which concentrates on individual components of an ecosystem and overlooks the interactions among these components. Ecosystems are more than air, water and land. They encompass organisms, including humans and how these organisms interact with the surrounding environment. A national ecological framework encompassing both terrestrial and marine areas of Canada provides a consistent national spatial context within which these ecosystems, at varying levels of generality, may be discussed and analyzed for environmental monitoring, analysis and reporting.

The national ecological classification of Canada is a spatial framework that serves as an important tool to facilitate the ecological approach to decision-making and resource management. For status and trend analysis of the health of our ecosystems, it is important to understand major ecological processes and how they may be affected by human activity. We must also understand these linkages at various ecological scales from the local to global. Sector classifications are well suited for specific purposes and have been designed to meet focused needs. As such, they have limitations for state of the sustainability reporting which must consider linkages between issues and among the various components of the ecosystem. The ecological framework takes a more holistic approach to delineation of the various ecological units. It considers both biological and physical ecosystem attributes in the determination of appropriate spatial units. It is the interaction of these various components of the ecosystem, at a given level of generalization, that identifies the spatial unit.

The basic premise for ecological classification in Canada is outlined in the document *Terrestrial ecozones of Canada* as compiled by Wiken (1986). It states that ecological classification is:

> "a process of delineating and classifying ecologically distinctive areas of the earth's surface. Each area can be viewed as a discrete system which has resulted from the mesh and interplay of the geological, landform, soil, vegetative, climatic, wildlife, water and human factors that may be present. This holistic approach to land classification can be applied incrementally on a scale-related basis from very specific to very broad ecosystems."

Ecological classification, for a given level of generalization, gives up specific detail found in single sector surveys in favour of more general data from several sectors. However, the advantages are several. With the emphasis on delineation of ecosystems, basic ecological interactions are captured allowing for a better understanding of key linkages and potential threats or impacts to these linkages. Basic descriptive data can be interpreted for a wide variety of applications. Since the information is assembled in one package, data retrieval is easy, efficient comparisons of different characteristics can be made, and a high degree of flexibility is available in making interpretations and modelling alternate impact or planning scenarios. Finally, as the classification is based on stable environmental attributes which reflect ongoing long-term processes, the products are useful for long-term ecological monitoring and assessment.

The methodology

The capture of ecosystems in map format is not an easy task. Ecosystems by their nature are dynamic and interact with other ecosystems. They are not entities with discrete boundaries. The task is to depict this complexity through appropriate mapping units. These units must be "workable", that is they must serve a useful planning and communicative purpose but at the same time have a scientific basis.

The concepts and hierarchy set out by the Canada Committee on Ecological Classification in the mid 1970s and 1980s are the overall guide for revising the three national levels of this hierarchy (ecozone, ecoregion and ecodistrict). These levels are the most useful to report on national issues and regional issues of national significance concerning the environment and sustainability of resources. The initiative was carried out in partnership with Environment Canada, Agriculture Canada, Natural Resources Canada (Canadian Forest Service) as well as the appropriate provincial and territorial jurisdictions. The task involved incorporation of the most recent provincial ecological mapping products in order to provide seamless national coverage at each level. Source documents included existing published maps particularly the ecoclimatic Regions of Canada (Ecoregions Working Group 1989), Physiographic Regions of Canada (Bostock 1970) and previous ecoregional delineations. Pre-existing ecodistrict coverage and the Soil Landscapes of Canada (Shields et al. 1991) served to modify the ecodistrict level of the hierarchy. Finally, Landsat imagery served as a broad correlation tool to integrate ecological units across provincial jurisdictional boundaries.

The determination of spatial units is an art as well as a science. At jurisdictional boundaries, line matching is sometimes an exercise in "scientific politics" whereby individual mapping biases give way to reluctant compromise.

In the end however, a seamless ecological map of Canada evolved with support from all jurisdictions - a feat not to be underestimated.

The product

Table 1 outlines, for the land base of Canada, the various levels of the hierarchy along with their respective definitions. Figure 1 provides a map of the terrestrial ecozones of Canada at the national level. For regional and specific project analyses, the hierarchy extends to detailed scales down to 1:10 000 and larger. For example, these detailed scales are used, by Parks Canada for ecological surveys of the national parks of Canada. Several provincial forest agencies as well use sub-divisions of ecodistricts to compile forest inventory information. A marine framework also exists comprised of five marine ecozones divided into various ecoregions and ecodistricts.

Canada is currently working with the office of the Commission on Environmental Cooperation (CEC), formed under the auspices of the North American Free Trade Agreement (NAFTA), to extend the ecological framework to cover the United States and Mexico. There is a strong desire by all three countries to produce an integrated ecological delineation of North America as a basis for analysis and reporting on common environmental concerns and issues.

Table 1. Hierarchy of the terrestrial ecozones of Canada.

Level of generalization	*Definition*	*Number of units*
Ecozone	Area of the earth's surface representative of large and very generalized ecological units characterized by various abiotic and biotic factors	15
Ecoregion	Part of an ecozone characterized by distinctive ecological responses to climate as expressed by the development of vegetation, soil, water and fauna	194
Ecodistrict	Part of an ecoregion characterized by distinctive assemblages of relief, geology, landforms, soils, vegetation, water and fauna	1030

Figure 1. *Terrestrial ecozones of Canada.*

Canada's Forest Inventory (CanFI)

As mentioned earlier, there are 416 million hectares of forest in Canada. Forest covers 42% of this large country where most resources are relatively remote and developments new. The forest is extremely important ecologically, economically and culturally and much of it has been covered by extensive forest inventories. Only about 29% of the forest area (12% of the country) is estimated as presently suitable, available and economically attractive for sustainable commercial wood production. Most of the forest management and human impacts are concentrated in this "wood production forest", and it is in this zone that the forest and associated ecosystems have received the most investment in forest inventories.

This zone of most activity is, in general, covered by well-maintained forest inventories suitable for forest management. It is here that most effort is now being applied to increase the scope of the timber-based inventories, so they become information systems also capable of catering to non-timber values and to more holistic forest management. However, the basic design of these inventories has concentrated typically on the most affordable map-based current information and on future projections. For reasons of economy and design, such inventories do not provide reliable time-series and estimates of trend.

As well as the geographical differences affecting forest inventory, there are jurisdictional differences. Forest management and inventory are primarily the constitutional responsibility of the ten provinces and two territories. Provincial forest inventories have much in common, but have resulted inevitably, in a variety of designs and specifications across the country. There is still a need for forest inventory information at regional, national and international levels for strategic decision support and general public information. To date, these needs have not justified the expense of an independent national sample. CanFI currently uses a set of national definitions, standards and conversion rules to "roll-up" the many source inventories to the national level.

The source inventories have a typical map scale of about 1:20 000. CanFI is spatial in that each provincial map sheet becomes a national cell of about ten thousand hectares. Within one cell, all of the individual stands (vegetation units) having the same national attributes are summed. This produces separate data records for each unique combination of national attributes occurring within a cell. The inventory collected in 1991 (CanFI91) contains over 47 000 cells. Normally, spatial analysis and map presentations are at scales of approximately 1:20 million, although other more detailed presentations are carried out.

The national attributes cover such things as: area, wood volume and growth, access, ownership, land class, forest composition, age and site class. Not all sources can provide all attributes, so special codes handle "missing" values (Lowe 1994; Gray and Power 1995).

The national inventory database is managed spatially (ARC/INFO) and relationally (INGRES). CanFI can be analysed using spatial and attribute criteria, and can produce an almost infinite variety of statistics. These can be presented as maps, tables or graphics. This form of database management allows other information to be related to the core inventory in three basic ways:

a) spatially related: e.g. identify the forest within X km of location Y.
b) attribute related: e.g. identify "old growth" forest according to certain criteria of composition and age.
c) spatially and attribute related. e.g. forest biomass relationships are being presently added to CanFI based on location and several descriptive characteristics of the forest.

CanFI is housed within the Canadian Forest Service. It is currently undergoing a physical shift from Petawawa National Forestry Institute, which is closing, to Pacific Forestry Centre in Victoria , British Columbia. CanFI will reopen for client service in the Fall with a capability to report statistics by province and territory, forest region and section and by ecozone and ecoregion.

Integration of CanFI with the ecological framework

In an effort to meld with databases associated with the national ecological framework and to pursue the broader interpretive potential of CanFI, CFS and Environment Canada jointly undertook to integrate CanFI with the national ecological framework. Before 1981, CanFI was a periodic aggregation of data with no spatial resolution below the provincial level. In 1981, the inventory took advantage of developing geographic information systems (GIS) technology, and of the map sheet structure of the source inventory databases, to introduce the cell level of resolution. Following creation of the 1986 inventory (CanFI86), this resolution was used to assign cells to forest regions and sections (Rowe 1972, Gray 1995).

Rowe's zonaton of Canada's forest is based on expected species composition and range and has been used by foresters for over fifty years. However, other disciplines use other regional criteria and until the terrestrial ecozones and ecoregions were developed, there was no standard national "ecological" classification for common reporting and the comparison of resource information. When ecozone and ecoregion boundaries became available in digital format in 1994 they were linked in the GIS to CanFI cells. The 217 ecoregional polygons are nested within 15 ecozones, so the cells are related to these polygons. Cells that fall into two or more ecoregional polygons are assigned proportionally. As a result, the inventory can now be analysed and mapped by ecozone or ecoregion just as if these units had been part of the original inventory.

The national ecological framework has the ecodistrict as its most detailed level of generalization. Currently, these ecological units, of which there are 1030, are considered too fine spatially to apply directly to CanFI. However, the ecodistricts share common boundaries with provincial ecological land units and, at the regional level, the ecodistricts are comprised of finer units. Provincial forest agencies are beginning to roll up the detailed inventories by these ecological units. Through the hierarchical nature of the national framework eventual compilations by ecodistrict should be available.

The CanFI GIS has been used to estimate total area of each ecozone and ecoregion for the whole country. Forest inventory results by these units are now being compiled for publication. Table 2 provides an illustration of such data.

Value-added by CanFI link to ecological framework

The national ecological framework is a nested hierarchy allowing reporting on sustainability from regional to national levels. This nested framework includes a database containing information from Canada's National Census such as status and trend statistics on population, labour force, and land use activity. Other databases include land cover derived from AVHRR satellite imagery, protected areas, and species at risk. The integration of CanFI fills a major vegetative void. Simple examples follow to illustrate the value of using and depicting forest inventory information in non-traditional ways. These applications serve not only to enhance state of the sustainability reporting in general, but reflect enhanced uses of timber inventories.

Communicating the science

The 1996 National State of the Environment report will use the ecological framework with inventory data to provide a synopsis of the status of old growth for parts of the country. Many caveats are associated with using age class alone to represent this important component of the forest. Other pertinent ecological data are lacking. However, the public wants to know now on its status. Age class is an useful surrogate, or starting point, to address this issue on which to build as pertinent ecological information become available.

Knowing the total area of "old growth" is not enough. There is a need for an ecological context, an essential component of biodiversity. For the Pacific Maritime ecozone, for example, old growth comprises about 35% of that ecozone and two-thirds of its timber productive forestland. With the addition of protected area information, an even more informative picture is presented on the status of this vital forest condition. The national ecological framework facilitates this integration of disparate databases for a more holistic view of old growth.

Table 2. *Canada's Forest Inventory: area by ecozone and land class (× 1000 ha).*

Ecozone	Forest			Non-forest land	Water	Land & water beyond the inventory	Total
	Timber productive	Not timber productive	All forest				
Arctic Cordillera	-	51	51	701	66	24 000	25 059
Northern Arctic	-	-	-	-	-	151 000	151 088
Southern Arctic	9	3 226	3 235	5 148	1 234	74 000	83 239
Taiga Plains	17 076	32 944	50 020	7 049	5 460	-	64 700
Taiga Shield	10 215	42 461	52 676	35 894	20 615	27 000	136 640
Boreal Shield	106 096	44 982	151 078	12 152	29 381	-	194 637
Atlantic Maritime	15 571	462	16 033	3 148	2 534	-	20 375
Mixed Wood Plains	3 301	353	3 655	7 419	6 273	-	19 443
Boreal Plains	33 798	16 019	49 817	15 270	8 651	-	73 780
Prairies	1 778	307	2 085	10 070	837	35 000	47 811
Taiga Cordillera	583	7 904	8 487	17 902	234	-	26 484
Boreal Cordillera	13 914	14 902	28 816	17 339	971	-	46 460
Pacific Maritime	8 563	1 494	10 057	10 200	402	1 000	21 898
Montane Cordillera	32 129	2 728	34 857	13 189	1 493	-	49 211
Hudson Plains	1 537	5 179	6 717	1 359	675	27 000	36 236
Canada	244 571	173 013	417 584	156 840	78 826	344 000	997 061

Old growth is only one issue high on the list of environmental concerns related to forest ecosystems as perceived by the public. Others include habitat loss, biodiversity and harvesting practices. Forest inventory data, particularly as the inventories begin to compile non-timber attributes, will become increasingly important as a baseline information source to address these issues.

Criteria and indicators

Environment Canada is charged by the federal government to develop a national set of scientifically credible, understandable indicators relevant to decision-makers and the public, that is representative of the state of Canada's environment, and indicates trends towards sustainable development. With the completion of the initiative to develop criteria and indicators of sustainable forest management, under the auspices of the Canadian Council of Forest Ministers, the task becomes one of integrating appropriate indicators of the many developed by CCFM, with the national set. To this end, three environmental indicator bulletins are planned for reporting on sustaining Canada's forests: timber harvesting, conservation of biodiversity and non-timber uses and values of the forest. The timber harvesting indicator bulletin is published with the other two due for completion by the end of 1996. Both the ecological framework and the integrated CanFI data are vital for the development and interpretation of these indicator bulletins.

For Canada, no criteria of forest sustainability can be monitored by one national indicator. For example, indicators of biodiversity must have an ecological reference. Total area protected for Canada is of limited value if there is no link to ecosystem representivity. Canada is too diverse to capture biodiversity change by a national level indicator. The nation is committed to protection of representative major ecosystems, including forested ecosystems. The ecological framework serves to outline these major ecosystems and desired levels of protection can be measured in the context of these ecological units. Similar arguments hold for other indicators of forest biodiversity such as species composition and age class, level of fragmentation, etc.

Integration of ecological databases

Requirements exist to report on sustainability at regional, national and international levels. The hierarchical nature of the ecological framework facilitates these levels of reporting while providing a consistent linkage among the three. Forest inventory data are input at the ecoregion level of generality. As the ecological classification, by its nature, is not a forest classification, it does not inherently define forest zones for Canada. However, for national reporting purposes the ecoregions can be amalgamated to delineate major zones such as the boreal forest. For example Canada's boreal forest comprises much of six ecozones and small proportions of others. Appropriate ecoregion subdivision breakdowns of these ecozones better delimit this boundary and, when rolled-up, provide statistics for the boreal forest. The integrity of the ecological polygons is maintained. Associated economic and environmental attributes of the ecological database can be compiled in the same manner to provide a more holistic synopsis of the boreal forest of Canada than CanFI alone.

There is a powerful link with the ecological framework to social and economic data compiled by Statistics Canada. That agency uses the national hierarchy as a common spatial framework for hundreds of variables related to population, labour force and the various natural resource sectors. Agriculture Canada has integrated its national soils database and related attributes with the framework. Other links include the National Forest Database Program, National Conservation Areas Database and internationally, with information bases of the U.S. EPA and EROS Data Centre of the U.S. Geological Survey.

Summary

Canada is a large and ecologically diverse country. In terms of natural resource planning, it is also a nation of many jurisdictions with their own priorities and planning frameworks. The juxtaposition and integration of federal planning and reporting requirements with similar provincial and territorial needs is not always straightforward. The national ecological framework for environmental reporting purposes provides a consistent national backdrop to allow such integration to take place. The hierarchical nature of the classification facilitates linkages between regional and national reporting and assessment needs. Comparisons among regions and, when appropriate, generalizations to the national level can be made. With extension of the classification to the continental level, encompassing the United States and Mexico, a common environmental reporting framework will be in place for much of North America.

Canada's Forest Inventory is the only national level biological inventory available that all the provinces and territories contribute to on a consistent and recurring basis. It has many caveats for general application, especially the shortage of non-timber information. Historically, forest inventories have been timber inventories. Such inventories are now changing and becoming broader forest ecosystem inventories. As these inventories improve so will the range of ecological attributes available for the national forestry database. However, in its present format, much valuable information for reporting exists. Integration with the national ecological framework allows for a different perspective on these data and facilitates application, because of a common spatial framework, with other national level ecological data for indicator development and environmental reporting.

Pressures are increasing both within Canada and from international agencies and groups to report on progress towards sustainable forest management. In Canada, the initiative through the Canadian Council of Forest Ministers to define criteria and indicators of sustainable forest management is complete. Implementation plans are being put into place. Undoubtedly, the onus will be on provincial and territorial forest inventory agencies to compile appropriate attributes from which the required indicators can be developed and tracked. The integration of CanFI with the national ecological framework facilitates a consistent, ecologically-based multi-disciplinary means of reporting progress towards sustainable forest management in a broader context of state of sustainability reporting. This integration also provides value-added to the forestry sector through access to a much broader ecological database for regional and national analyses of forest ecosystem health.

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MULTI-SOURCE NATIONAL FOREST INVENTORY OF FINLAND

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Abstract

The National Forest Inventory of Finland has produced large-area forest resource information for over 70 years. Line transect sampling, systematic cluster sampling and, in North Finland, two-phase stratified sampling with aerial photos and ground sample plots have been employed. The Finnish Forest Research Institute started to develop a new inventory system in 1989, during the eighth inventory, in order to obtain geographically localized, up-to-date information and for areas smaller than earlier. The method exploits satellite image data (Landsat TM), digital map data and, in the future, other geographical data, e.g. soil and meteorological data, in addition to the ground measurements. Image analysis methods have been chosen in such a way that estimates of all variables of the inventory can be computed for each pixel. The system is now operative and the inventory has been applied to an area of about 16 million hectares, producing theme maps and statistics for large and small areas. The data for the whole country will be ready in 1995.

The most serious problem in the application of the method are clouds which often prevent from obtaining imagery of a target area from a specific year. Therefore, a study for developing methods for utilization of ERS-1 SAR -data in large area inventories has been started together with the Space Laboratory of the University of Technology and with a support of ESA, AO -project PP-SF1. Use of other remote sensing data such as airborne scatterometer and imaging spectrometer data are also being developed.

National Forest Inventory has traditionally produced information about biodiversity. Recently, a wide research program for introducing theoretical concepts and measures for assessing biodiversity, its development and factors affecting it has been started with the University of Joensuu.

The multi-source inventory method developed by the Finnish Forest Research Institute has been tested also in foreign countries.

Keywords: Forest inventory, satellite imagery, digital map data

1. Old National Forest Inventories

Slash-and-burn agriculture, burning of wood to make tar, household use of timber, ship building and, from the second half of nineteenth century, an increasing forest industry exhausted Finnish forest resources. According to the pre-inventory documents, the forest resources of Finland were at their lowest level when raising of crops on burnt-over clearings ended, around at the turn of the century.

The first National Forest Inventory (NFI) was started against this background at the beginning of 1920's, shortly after the declaration of Finland's independence. The inventory was led by Yrjö Ilvessalo, professor of forest inventory at the Finnish Forest Research Institute and later a fellow of the Academy of Finland. The areas of site and stand classes were estimated by means of line measurements. Growing stock characteristics were estimated from sample plots laying on lines. Lines ran from southwest to northeast at intervals of 26 kilometers, (Ilvessalo 1927). The methods in the following second (1936-38), third (1951-53) and fourth inventories (1960-63) were almost the same as in the first inventory, except the sampling density.

Detach L-shaped tracts have been employed instead of continuous lines since the fifth inventory (1964-70), the first inventory lead by Kullervo Kuusela (Kuusela and Salminen 1969). This design is statistically more effective and was also favoured by improved road network. At the same time, inventories became continuous, and proceeded by regions from south to north. Fixed size sample plots were also changed to Bitterlich plots. Another new feature in the 5th (1964-70), 6th (1971-76) and 7th (1977-84) inventories was the use of aerial photographs in North Finland. The Finnish Forest Research Institute (FFRI) has been responsible for all the inventories.

During the eighth rotation (1986 - 1994), the FFRI developed a multi-source inventory system which utilizes satellite images and digital map data in addition to ground measurements.

A lot of information other than growing stock and increment is collected in National Forest Inventories. Examples are information on forest health and ground vegetation, animal observations in some inventories for estimating species distribution, and bryophyte samples for analysing the distribution and concentrations of sulphur and heavy metals.

2. The recent multi-source inventory

Rapid changes in forests in the 1980's and the importance of the role of the forest sector in the Finnish economy were the main reasons behind the further development the inventory method. On the other hand, new technology has given new sources of forest information and has made it possible to increase the cost efficiency of an inventory and to acquire better localized information and for smaller areas than what is possible with field measurements only.

The Forest Research Institute started to develop a new inventory system in 1989. Satellite images and digital map data have been employed in an operative way with the sample plots of 8th inventory since 1990. Other geographical and meteorological data will be introduced later.

2.1 Field sampling system

Field sample plots are utilized for estimating results for large areas and as ground truth data in satellite image processing. Also the field sampling system has been renewed during the eighth rotation. The revised system has applied from the summer of 1992, north from the administrative border of northern Finland.

The distance between two tracts varies from south to north, with the density and variableness of forests and is 7 kilometers both in north-south and east-west directions in Central Finland. One tract has 15 sample plots, of which three are permanent and the other twelve temporary (Tomppo 1993). Global positioning system (GPS) with real time correction and radio data system (RDS) has been recently introduced. It allows, in addition to localization of sample plots, a navigation to the plots.

The coordinates of the trees on permanent plots are registered in order to identify them during the next inventory.

A Bitterlich sample plot is applied. Tallied trees are selected with a relascope, the relascopic factor varies by region, from south to north and west to east, depending on the density of the forests and is 1.5 in Central Finland. The maximum radius is 12.45 meters (corresponding to the breast-height -diameter 30.5 cm with the factor 1.5). Reducing the radius of a sample plot decreases the reliability of estimates very little, but decreases in some cases the amount of field work noticeably, because the number of divided sample plots decreases. Every 7th tally tree is measured as a sample tree (Tomppo 1993).

2.1.1 Processing of field data for multi-source calculations

Multi-source data are utilized for estimating new area weights for field sample plots and for producing digital thematic maps, in principle for an arbitrary variable of the National Forest Inventory (NFI). Examples of maps are spatial distributions of site fertility, mean age and diameter of stand, volumes by tree species and timber assortments and volume increment of growing stock by tree species.

The basic computation unit in image processing is a picture element, a pixel. The pixel size applied with Landsat TM images, e.g., is 25 m × 25 m. Therefore, it is more convenient to work with volumes per area unit than with volumes of tallied trees or their *Vu* -values, i.e. volumes of trees per basal areas. Volumes per hectare are estimated for each sample plot by tree species by the formula:

$$v_t / ha = 4q / \pi \sum_{i=1}^{n} Vu_{i,t} d_i^2, \tag{1}$$

where q is the relascopic factor, $Vu_{i,t}$ is the Vu -value for timber assortment t and d_i the 1.3 meter height diameter of the tree i and n = number of tally trees measured on the plot.

Volume increment of tally trees must be estimated in order to obtain plot level volume increment estimates. Field measurements based result computation does not involve increment estimates of tally trees.) Regression models of increments by tree species are estimated as a function of tally tree and stand variables employing measured sample tree data.

2.2 Preprocessing of satellite images

The most feasible satellite image data are, at this moment, Landsat TM, Spot and MOS-1 images. So far, mainly TM and, to minor extent, Spot images have been applied. One TM image covers a larger area than one Spot image making it more likely to yield cloud-free images covering the inventory area. The utilization of space-borne radar data is under research.

Satellite images from the growing season of the field measurements are applied, if possible. Images acquired in late June are optimal for site fertility classification and tree species differentiation in southern Finland. Clouds prevent the acquisition of such imagery very often. Even images from different year than the field measurements have to be applied sometimes. In such cases, field data must be updated. Each single image scene must cover the area to be inventoried in such a way that the number of sample plots covered by the scene is high enough, preferably at least 2000.

Satellite images covering the inventory area will be geographically rectified on the base map. For each image, 20 - 30 control points which can easily be recognized both on the map and the image are picked up for the rectification.

Regression models of first or second order polynom will be estimated for the unrectified image coordinates, (lin, col), as a function of map coordinates, (x,y). The intensity value for each pixel of the rectified image is found usually by the nearest neighbour method. The model of a second order polynomial is of the form:

$$\begin{aligned} lin &= a_l + b_l x + c_l y + d_l x^2 + e_l y^2 + f_l xy + \varepsilon_l \\ col &= a_c + b_c x + c_c y + d_c x^2 + e_c y^2 + f_c xy + \varepsilon_c \end{aligned} \tag{2}$$

Pixel size of 25 m × 25 m is chosen in the rectification phase. The residuals of the model are in most cases less than 0.4 pixels in the directions of the line and column and less than 0.5 pixels in the direction line × column.

The nearest neighbour method does not change the intensities of the image wherefore the method is applied instead of the bilinear or cubic convolution -methods.

Destriping, removal of noice and calibration of images against the effect of atmospheric variation and gain decay of sensors would be other possible preprocessing operations. These operations have not been applied in the operative image processing so far.

2.3 *Processing of the ground truth data*

Let us call 'plot pixel' a pixel whose centerpoint is geographically closest to a field sample plot. The intensity values of a $n \times n$ -window of satellite image are added to each sample plot in the processed the field data file. The $n \times n$ -window is chosen in such a way that the central pixel is the plot pixel. The value 3 is usually applied for n.

Same intensity values are added for each part of the sample plot if the plot is divided into several stands. (In fact, the different parts of a plot are not separated in the process.)

Plots with accomplished cutting after the image acquisition date are removed from the ground truth data if the image has been taken earlier than the field measurements have been carried out. The sample plots which have been clear-cutted after the measurement of the plot are identified by a comparison of fitting of growing stock volumes in the field data and intensity values of the plot pixels if the image has been acquired after the field measurements. The plots clear-cutted after the date of the image acquisition are removed from the ground truth data.

Sample plots covered by clouds or their shadows are omitted from ground truth data.

2.4 *Digital land use data*

It is not possible to separate all land use classes from forestry land reliably enough with satellite image analysis. For example, built-up areas can be mixed with forestry land while young (hay growing) forest regeneration areas can be mixed with arable land. Furthermore, the accuracy of estimates based on image analysis can be improved if swamp areas could be separated reliably from mineral soils using other information sources than satellite images, e.g. digital maps. Mineral soil sample plots could then be applied on mineral soils an vice versa. In addition, the reliability of image analysis can be improved by means of digital elevation model (DEM).

Arable land, urban areas, single buildings, roads, swamps and digital terrain model are in digital form, at the moment. Some administrative information such as municipal boundaries, boundaries of areas of ownershipsgroups and, in the future, boundaries of forest holdings will also be used in digital form in order to differentiate computations units. Water areas could be obtained from base maps but they can be obtained relatively reliably from satellite images as well as peat production areas, when they are not available on maps. Digital map data are transformed into raster form.

1) Arable land

The information on arable land is based on the base map of the scale 1:50 000. The yellow arable land element has been scanned by National Land Survey of Finland with a pixel size of 25 m × 25 m. A transformation to the zone of 27 degrees is carried out, if the original Gauss-Gruger projection zone differs from this.

At the moment, pure map data have been used for the separation of land classes. A combination of a digital satellite image analysis and digital map information will be used in the future for classifying agricultural areas, because the map data are not necessarily up-to-date.

2) Urban areas and buildings

The information on built-up land is obtained from the housing register provided by the Civil Register of Finland. The coordinates of each house in Finland are known. This information can be utilized for producing a mask of land occupied either by urban areas or detached houses.

A group of houses with at least 200 inhabitants and with a within houses distance at most 200 meters form an urban area and are combined into a connected built-up land. These vector form data are purchased from Statistical Centre of Finland and is converted into raster format.

Buildings outside build-up areas are presented as squares of a size of 2 × 2 pixels. The four pixels which are closest in the geographical space to the house and which compose a square are applied.

3) Roads

The road maps are received from National Land Survey of Finland in vector files of DXF-format. The coordinates of corner points of roads are listed in the file. The points of vector file is connected to solid lines using and transformed into a raster-file. At the beginning, all roads were of width of 25 meters. Recently, a new system has been introduced. Roads are classified by means of road class number and the width of each road in the raster file depends on the class, varying from 25 to 100 meters.

4) Digital boundaries of computation units

The computation units in ordinary image processing are municipalities. Digital municipal boundaries have been purchased from the National Land Survey of Finland with a format of FINGIS -transfer file. The boundaries have been digitized from maps with a scale of 1:10000. For image processing, the vector format file are converted into raster format in such a way that the intensity value of a pixel is the same as the index number of that municipality which involves the pixel.

Result computation is needed often by request for some other computation units than municipalities, for instance for different ownershipgroups by municipalities or even for forest holding of a single owner.

The main ownershipgroups in Finland are private owners (63 % from the area of forest land) state, forests managed by Finnish Forest and Park service (24 %) and forest industry companies (9 %).

The task is thus to separate state and companies owned forests from private owned forests. There are several optional methods for this purpose. A part of forest holding boundaries of forests of Forest and Park service are already in a digital form. In other cases, digitizing of boundaries with a coordinate reader or scanning of colour elements of a map which indicates certain ownershipgroups or an ownership (e.g. forest industry company) can be used.

For image processing, administrative units and owner groups are transformed into raster format.

5) The digital terrain model

Digital elevation model are used for correcting original spectral values in order to avoid confusion in image analysis caused by land morphology. The model of the entire country has been bought from National Land Survey of Finland. It is of a raster format file with the pixel size of 25 m x 25 m and with the resolution of 10 cm. This file has produced from the original elevation contour of the Finnish base map. The original contour interval has been either 5 or 2.5 meters.

The angle α between the normal to the land surface and the sun illumination angle at the time of the satellite overpass is used in correcting the observed spectral values. The dependence of the normalized spectral value I_n on the angle α and the original spectral value I is assumed to be of the form

$$I_n = I / \cos^n(\alpha), \tag{3}$$

where $0 < n \leq 1$ and is indicating the deviance of forest from Lambertian surface.

The value of n is found by a system of trial and error using cross-validation technique with sample plots and mean square errors as criteria. Let us denote the sun azimuth by $ø$, running from south to east and the sun elevation angle by q, running from vertical to horizontal. The unit vector towards the sun is thus

$$(x_s,y_s,z_s) = (sin(\theta)cos(ø), sin(\theta)sin(ø), cos(-\theta))$$

and the surface normal unit vector

$$(x_n,y_n,z_n) = (i_x/s, -i_y/s, 2d/s),$$

where

$$i_x = e_{i-1,j}-e_{i+1,j}, \; i_y=e_{i,j-1}-e_{i,j+1}$$

and

$$s = \sqrt{i_x^2 + i_y^2 + 4d^2}.$$

According to a well-known fact $cos(\alpha) = x_n x_s + y_n y_s + z_n z_s$; cf Tomppo (1992).

The output raster type file includes as a result for each pixel the original elevation from sea level, slope, aspect and the angle a between sun illumination and terrain normal. These variables are also added to the sample plots of the ground data file.

In addition to intensity value corrections, the absolute elevation from the sea level is also utilized in the classification phase in such a way that a maximum distance in the elevation direction is set from the pixel to be classified to the ground sample plots applied ground truth.

6) Peatland

The spectral response of peatlands differs from that of the mineral soils with the same growing stock. Further, some peatlands can not be separated from mineral soils. Therefore, digital peatland information is used in order to improve the accuracy of estimates.

Data on peatlands has been scanned from basic maps (scale 1:100,000) or GT-maps (scale 1:200,000). The data is provided by the National Land Survey of Finland in raster format. Tests have shown, however, that this data is not always reliable enough to be used in the image processing as such.

If the peatland mask would be reliable enough, sample plots classified in the field to be included in peatland could be applied in analysing the forest area under peatland mask and vice versa. Peatland mask is not yet reliable enough to be used in this categorical way. All peatland area is not covered by the mask and sometimes the mask covers a part of mineral soil. If applied in the categorical way, the mask would cause wrong peatland area estimates. Therefore, peatland mask is utilized in image processing in such a way that sample plots laying on pixels which belong to the peatland mask is applied with those pixels which belong to the area of peatland mask and vice versa.

This means that a stratification for both the sample plots and the satellite images is carried out by means of peatland mask (not by means of field observed peatland class for the sample plots) and the strata are processed independently.

7) Clouds

In some cases clouds and/or their shadows cover a part of the image to be processed. The total area of the image affected by clouds or their shadows are delineated. A colour composition of visible channels (TM -channels 1, 2 and 3) of the image are transferred to the display unit of a workstation and enhanced in such a way that also crepelike clouds and their shadows can be visually recognised as well as possible. The areas are surrounded (manually with a mouse) by polygons. These polygons are transformed into a 1-bit raster file. This raster file is an optional input file in combining intensity values to ground sample plots and in image processing. The sample plots whose intensities are affected by clouds or shadows are left out from ground truth data.

The pixels affected by clouds or shadows are not processed in the image analysis. The forest area under clouds or shadows is assumed to be similar to the average of the rest of the computation unit (e.g. municipality).

8) Water

Water areas are delineated by the information of satellite images at the moment. This information is quite reliable for the purpose. Channels 4 and 7 of Landsat TM images and tresholding are employed. A pixel p is classified as water W by the rule:

$$(p \in W \mid f_4(p) \leq k_4, f_7(p) \leq k_7). \quad (4)$$

The parameters k_4 and k_7 are chosen for each image in such a way that the area classified as water equals to the water area found in statistics of National Land Survey of Finland.

9) Peat production areas

Some of the peat production areas are delineated on maps. These areas are digitized and processed like any other pixels on non-forestry land. If data on peat production areas are not reliable or complete, digital classification is used. Reference areas are taken on one hand from such land that can reliably be classified as peat production area and on the other hand from forestry land. Reference areas and discriminant analysis based on generalized squared distances are used for classification of peat production areas. DAN program developed by METLA is used for discrimination.

2.5 Estimation of parameters by means of multi-source data

Four or five input files are produced for the classification as described above. The files are: 1) ground truth file (an ASCII -FILE), 2) satellite image file, 3) digital land use data (map data) plus computation unit file, 4) digital terrain model involving information about sun illumination angle and, if necessary, 5) cloud mask file.

A device independent utility has been programmed for image processing, running today e.g. on DEC/ULTRIX and AXP/OSF-1 operating systems. The utility reads first the ground truth data into RAM-memory. The image is processed line by line. The utility reads one line at a time (or several lines if spatial features are applied) from each raster-format input file (satellite image, land use and computation unit file, DTM and cloud mask -file) into the RAM -memory. The pixels of the actual line are processed turnwise. The utility searches for each pixel of the line *k* 'nearest' pixels with known ground truth data (=pixels with sample plots). The whole ground data vectors from *k* searched sample plots will be attached to the pixel. The ground data vectors are weighted inversely proportionally to the squared distance in the feature space. The essential property of the process is that all inventory variables can be 'estimated' for the pixel at the same time. The idea of using *k* sample plots instead of one is to reduce the random variation caused e.g. by image noice. Let us call the method a **k-nearest neighbor classification** method.

The procedure can be described more formally in the following way. The Euclidean distance, $d_{p_i,p}$, is calculated in the feature space from the pixel p to be classified to each pixel p_i whose ground truth is known (to pixel with sample plot i). k nearest sample plot pixels is taken **in the feature space** and the distances from the pixel p to the nearest sample plot pixels are denoted as $d_{(p_1),p}, \dots ,d_{(p_n),p}$, ($d_{(p_1),p} \leq \dots \leq d_{(p_n),p}$), $n \sim 5$ - 10. A maximum distance in the geographical space (usually 40 to 100 km in horizontal direction) is set from the pixel p to sample plots applied in order to avoid using sample plots from very different vegetation zones. A maximum distance is also set in the vertical direction by means of DTM, usually 50 to 100 m, in order to take into account the vegetation variation caused by elevation variation. Let us define

$$w_{i,p} = \frac{1}{d^2_{(p_i),p}} \Big/ \sum_{j=1}^{n} \frac{1}{d^2_{(p_j),p}} \tag{5}$$

Sums of weights, $w_{i,p}$ are calculated by computation units (for example by municipalities, by forest ownershipgroups, by private owners in a certain municipality, etc.) in the classification process. (The relative weight of a plot equals to the plot factor when results are computed by means of field data only.)

The weight of the plot i in the computation unit u yields:

$$c_{i,u} = \sum_{p \in u} w_{i,p} \tag{6}$$

Estimates for some (optional) forest variables are written in the form of a digital map during the procedure. The estimates are written after each processed line are in the form of a multichannel raster image. The land use classes outside forestry land are transferred directly from a digital map file. Within forestry land, the variables entered by the operator are estimated in the following way.

The estimate $\hat{m}_p$ of the variable M is defined for the pixel p

$$\hat{m}_p = \sum_{j=1}^{n} w_{(j),p} \cdot m_{(j),p} \tag{7}$$

where $m_{(j),p}$, $j=1,...,k$, is the value of the variable M in the sample plot j corresponding the pixel $p_{(j)}$ which is j^{th} closest pixel of 'known' pixels in the spectral space to the pixel p, see Tomppo (1991). Mode value is used instead of mean value for qualitative variables.

The often computed variables in the course of the image process are growing stock volumes by tree species, increments by tree species, site fertility class, mean age, etc.

Stand level results can be computed (by request) utilizing given stand delineation. Stand delineation can be carried out optionally by means of segmentation techniques. Segmentation can also be used for improving small scale estimates, i.e. for reducing variation caused e.g. image noise. Another post-processing method is mathematical modelling e.g. by spatial Gibbs -type processes (Tomppo 1992).

2.6 *Compilation of statistics and map production*

The inventory results by computation units are obtained by means of digital maps and the weight coefficients (6) of the field sample plots estimated in the image process.

The area of water and non-forestry land use classes are estimated by computation units from the produced digital maps by multiplying the number of pixel classified in the land use class by the size of the pixel:

$$A_{c,u} = \#\,(p \mid p \in c, p \in u)\, a, \tag{8}$$

where C is a land use class, U a computation unit and a the area of one pixel.

The non-forestry land area under a possible cloud mask can be estimated in a similar way, because land use class estimates outside forestry land are based on the pure map data. The water area under cloud mask will be taken in the future from digital maps as well.

The area estimates for forestry land strata by computation units are obtained from the estimated plot weights by the equation

$$A_{s,u} = a \sum_{i \in I_s} c_{i,u}\,, \tag{9}$$

where s is a forestry land stratum, I_s the set of sample plots of the stratum and u a computation unit.

The weights $c_{i,u}$ of all plots i in the computation unit u are multiplied by the factor *total forestry land area of the unit / (total forestry land area - forestry land area covered by clouds)* if clouds cover a part of the forestry land area. This means that it is assumed that forest area covered by clouds is on average similar to other forests in the unit.

The volume estimates are computed by computation units and by strata in the following way. Mean volumes are estimated by the formula

$$v = \frac{\sum_{i \in I_s} c_{i,u} v_{i,t}}{\sum_{i \in I_s} c_{i,u}}, \tag{10}$$

where s is a computation strata (e.g. site fertility class), I_s the set of the sample plots in the strata, u a computation unit (municipality), $c_{i,u}$ the weight of the sample plot i in the unit u and $v_{i,t}$ the volume per hectare of the timber assortment t on the sample plot i.

The corresponding total volumes are obtained by replacing the denominator in the formula (10) by 1. Mean and total volume increment are estimated respectively.

Colour hardcopies is one way to present inventory results. An electrostatic Versatec 8900 color plotter is employed for this purpose. A digital theme map is first transformed into VCGL -format. The result is transferred into the disk of plot server from which it is transferred to the plotter.

An edge preserving smoothing is applied before VCGL -transformation. It computes the local variance within different windows and chooses that with the minimum variance. The filtering reduces the within stands variation and makes the map easier to interpret. The thematic map is classified in classes defined by the user during the VCGL -transformation procedure. The user also selects the colors used for different classes and describes the legend of the map.

3. *Reliability of estimates*

The reliability of estimates can be assessed statistically and empirically. The standard errors of some characteristics (caused by sampling) for the whole country in the 7th inventory are: proportion of forest land 0.4 %, total growing stock 0.7 % and total increment 1.1 %. The corresponding figure for a typical computation unit (1.2 million ha) are 1 %, 2 % and 3 %. Computations using results from successive inventories also confirm the reliability of the results. Adding the increment of a new inventory to the volume of the previous inventory and subtracting the removals has usually given a figure that differs from the measured volume of the new inventory by less than 1 %. For instance, the estimates in the

6th inventory of the initial growing stock and increment were (in million m^3) 1519.5 and 69.4 while the total removals were 334.2 yielding 1654.7 which is 0.5 % less than the measured estimate 1663.6 in the 7th inventory.

Methods to assess statistically the reliability of multi-source estimates are under development.

4. *Further research*

4.1 Microwave instruments in inventories

The most serious problem in applying the satellite image based multi-source inventory method are clouds which often prevent from obtaining images from the growing season of field measurements. This difficulty can be avoided with microwave instruments.

A large cooperation project with the Laboratory of Space Technology at the Helsinki University of Technology has been started. The objective is to test the applicability of SAR -images (synthetic aperture radar -images) of ERS-1 satellite of European Space Agency and the scatterometer (HUTSCAT) developed by Space Laboratory in large area forest inventory.

HUTSCAT is a helicopter-borne high-resolution ranging scatterometer (operating at 5 and 10 GHz, 4 polarizations) which has turned out to give very accurate estimates for some forest characteristics (e.g. mean and dominant height).

Six test areas, three in Finland and one in each of Canada, China and Russia have been chosen for the study. Soil moisture measurements have been carried out in a subset of the inventory plots because it has turned out that moisture affects heavily on the backscattering coefficient. A digital terrain model and multi-temporal imagery throughout the year are used in the data processing. The results show that by means of multi-temporal ERS-1 SAR images it may be possible to have information for forestry purposes.

4.2 Biodiversity studies

A system for measuring biodiversity of forests in national and regional inventories will be developed in another large research project. This is a cooperation project with National Forest Inventory, University of Joensuu and European Forest Institute.

There are four subprojects in the study:

1. Development of methods for measuring biodiversity based on forest characteristics, habitat occurrence and statistical-ecological methods.

2. To study the effect of stand structure and silvicultural treatments on the biodiversity and occurrence of species.
3. To analyze of the history of land use during the time originating the present structure and diversity of forests, i.e. from the beginning of 1800's The interesting land use types are settlement, slash-and-burn cultivation, making of tar and charcoal, pasturing, use of timber and silviculture.
4. To study the effect of forest fire frequencies and land-use history (slash-and-burn cultivation) on forest biodiversity. In the dendrochronological approach, fire-scars present in live and dead trees will be analyzed in order to develop local forest fire histories covering the past c. 500 years for the chosen study site. Analysis of annually laminated lake sediment sequences will give information about natural fire frequencies and related vegetation changes from the past 2 - 3 millennia, i.e. for the time before any significant anthropogenic influence.

The study will last until the end of 1996, but it should be able to apply the methods already in the 9th inventory which will start 1996.

The use of imaging spectrometer (AISA) will be studied in assessing biodiversity of forests in the new project started in 1995.

4.3 Imaging spectrometer research

The FFRI has recently purchased an airborne imaging spectrometer (AISA) developed by Technical Research Centre of Finland and Karelsilva. It uses pushbroom type CCD sensor matrix. The wavelength is from 450 to 900 nm, bandwidth from 1.6 to 9.4 nm, number of channels from 1 up to 288. Minimum integration time is 4 ms, the pixel across track 0.001 × flight height and pixel along track integration time × speed. A typical pixel size can be e.g. 1 m × 1 m.

Compared with the old multiscanner instruments, imaging spectrometers provide totally new application possibilities. With the help of spectrometers, it is possible to recognize a phenomenon visible in very narrow spectral bands, e.g. early stresses of trees. Also possibilities to accurate stand level forest inventories are good. The instrument can be programmed suitable for specific applications.

The AISA instrument has turned out to be very promising compared with all other spectrometers available today. The research for operationalising the instrument for forest inventory, forest health and forest biodiversity monitoring has been started recently. The objective is to develop a multi-source inventory method both for small and large areas.

Conclusions

Finland's forest resources have been investigated trough National Forest Inventories for over 70 years. Finland has longer time series about changes in its forest than any other country in the world. The information has provided a firm foundation for planning Finland's forest industry and the utilization and management of forests. The inventory method will change gradually from repeated temporary field inventories to an up-to-date, multi-source resource, health and biodiversity monitoring and forest management planning system.

The multi-source inventory method developed by the Finnish Forest Research Institute has been tested, or negotiations about the application are going on, also in some other countries like Sweden, Germany, New Zealand and China.

The future forest inventory, involving forest health and biodiversity monitoring, can be possibly based on the co-use of field measurements, airborne instruments, such as imaging spectrometers, scatterometers and satellite images of optical and microwave area. The roles of different input information sources vary depending on the application and information need. This kind of a system will have very wide international application possibilities.

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SEQUENTIAL ACCURACY TESTS FOR THE APPLICABILITY OF EXISTING EQUATIONS

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Abstract

To determine whether an existing equation is acceptable for application to a new species, a new region, or a local area, an accuracy test could be carried out. Parametric and nonparametric sequential accuracy tests were developed which utilize the differences between observed values versus those produced using the existing prediction equation,obtained by sequentially sampling the new population.The parametric tests are extensions of Freese's (1960) fixed sample size accuracy test using Wald's (1947) sequential probability ratio tests (SPRT); therefore, a normal distribution of differences is assumed. The nonparametric tests are based on a transformation of the differences to a binomial distribution. The basic parametric and nonparametric tests were derived to test the precision of the equation when applied to the new population. Since bias may also be present, modifications were also derived to test precision after bias removal. Monte Carlo simulations were used to examine the reliability of the sequential accuracy tests using a range of normal distributions and test parameters, and using a selection of non-normal distributions. A summary of the results of the simulations and an example to illustrate the use of the tests are presented.

Key words: Accuracy tests, statistic

Introduction

Prediction equations are commonly used for many aspects of forest inventory. These equations are developed for a particular population using sample data from that population. Often, the fitted equations are considered for use in another similar population, such as for a similar species in the same area, or in a subpopulation, such as a local area within the original population area. To avoid using equations with unacceptable accuracy (bias and/or high variance), the existing equations could be tested using data from the new or sub- population. Fixed sample size procedures were developed to test the accuracy of an existing equation when applied to a new population (e.g., Freese 1960; Gregoire and Reynolds 1988). However, a decision on whether to accept or reject the equation may be made with fewer observations if a sequential sampling (variable sample size) procedure is used. This is particularly useful when the collection of appropriate data requires expensive measurements or destructive sampling.

A description of parametric and nonparametric sequential sampling accuracy test procedures that were derived for testing the accuracy of the existing equations when applied to another population (Brack and Marshall 1990; Marshall and LeMay 1990; Wang 1994) are presented in this paper. As with Freese's fixed sample size accuracy test (1960), these sequential accuracy tests utilize the differences (d_i) between the observed values from the new population (y_i) and the predicted values using the existing equation ($\hat{y}_i$). Using Monte Carlo simulation, the average sample size using the parametric tests versus using Freese's test when the underlying distribution of differences is normal was examined. Monte Carlo simulations were also used to examine the reliability of the sequential accuracy tests using a range of normal distributions and test parameters, and using the same selection of non-normal distributions used by Gregoire and Reynolds (1988) to test Freese's fixed sample size accuracy test (1960). A summary of the results are given here. More detailed results are available from the authors, and have been submitted for publication in the Canadian Journal of Forest Research (Wang and LeMay 1995; Wang, LeMay, and Marshall 1995). An example is given to illustrate the use of the tests.

Parametric sequential accuracy tests

Description of tests

Freese's accuracy test (1960) was used as the basis for deriving the parametric sequential accuracy tests (Wang 1994; Wang and LeMay 1995), along with Wald's Sequential Probability Ratio Test (SPRT) (1947). For Freese's fixed sample test, an error limit, e, and an associated probability (1-γ) must be specified. The equation is then considered sufficiently accurate if $P(|d_i| \le e) \ge 1-\gamma$. If the differences are normally distributed with a mean difference of zero (no equation bias), this is the same as testing the hypothesis that the variance of the population is less than or equal to $e^2 / z^2_{1-\gamma/2}$, the variance limit, where $z_{1-\gamma/2}$ is the $(1-\gamma/2)\cdot 100$ percentile of the standard normal distribution.

For the parametric sequential accuracy tests, two error limits under the null and alternative hypotheses must be specified, e_0 and e_1, along with γ. Also, the Type I and Type II error probabilities, α and β, must be specified. The value e_0 may be interpreted as the upper limit for model acceptability, whereas e_1 is the lower limit for model rejection, and e_1 is greater than e_0. Under the assumptions of zero bias and a normal distribution of differences, the hypotheses to be evaluated using the parametric sequential test are:

$$H0:\ \sigma^2 = \sigma_0^2 = e_0^2 / z_{1-\gamma/2}^2$$

$$H1:\ \sigma^2 = \sigma_1^2 = e_1^2 / z_{1-\gamma/2}^2$$

The test statistic for the hypotheses is:

$$T_1 = \sum_{i=1}^{n} d_i^2$$

where n is the sample size at that stage in the sequential sampling procedure. Using the specified α and β levels, the two error limits, and γ, two parallel decision lines can be derived by:

$$\textit{Line 1:}\quad h_1 + s \cdot n$$

$$\textit{Line 2:}\quad h_2 + s \cdot n$$

where

$$h_1 = \frac{2 \cdot \ln\left[\frac{\beta}{1-\alpha}\right]}{1/\sigma_0^2 - 1/\sigma_1^2}$$

$$h_2 = \frac{2 \cdot \ln\left[\frac{1-\beta}{\alpha}\right]}{1/\sigma_0^2 - 1/\sigma_1^2}$$

$$s = \frac{\ln\left[\frac{e_1^2}{e_0^2}\right]}{1/\sigma_0^2 - 1/\sigma_1^2}$$

$$e_0 = \sigma_0 \cdot z_{1-\gamma/2}$$

$$e_1 = \sigma_1 \cdot z_{1-\gamma/2}$$

where h_1 and h_2 are intercepts for the two lines, with $h_1 < h_2$, and s is the common slope.

To implement the test, a random observation is drawn from the application population. If $T_1 \leq h_1 + s \cdot n$, the equation is accepted. If $T_1 \geq h_1 + s \cdot n$, the equation is rejected. Otherwise, no decision is made and sampling continues. The procedure can be modified to stop sampling when an upper limit for sample size is reached, or to sample a group of observations rather than a single observation at each stage. Also, relative differences (differences divided by the observed values) could be used, if the relative differences rather than the actual differences were normally distributed.

If equation bias is present (the average difference is not zero), the same test procedure could be used. However, the differences will reflect both the bias and the precision of the estimates. An equation could be rejected because of biases, even if the variance of the differences is small. As with Freese's accuracy test (1960), a modification of the test statistic could be used to test accuracy after bias removal. The modified test statistic is:

$$T_2 = \sum_{i=1}^{n} (d_i - \bar{d})^2$$

In addition to modifying the test statistic, the decision lines must be modified by using *n-1* instead of *n*.

Reliability and average sample size

A test may be considered reliable if the achieved probabilities of Type I and Type II errors (α and β) are at or below the specified nominal levels. Monte Carlo simulations were used to test the reliability of the parametric sequential accuracy tests for differences that follow a normal distribution with a zero mean (Wang 1994; Wang and LeMay 1995). For a wide range of error limits, different α and β levels, and differing γ levels, the actual probabilities of Type I and II error levels were below the nominal values specified. For differences following a normal distribution with a non-zero mean, the correction for bias produced reliable results for a range of biases (mean differences). Also, the expected reduction in sample sizes for these tests over Freese's fixed sample size accuracy test (1960) ranged from 40 to 60 % based on simulations using normal distributions. However, using the same non-normal distributions as used by Gregoire and Reynolds (1988) to test the robustness of Freese's accuracy test (uniform distribution, double exponential distribution, and a 9 to 1 mixture of two normal distributions), the parametric test was found to be not reliable, in that the error probabilities were greater than their nominal values. This was particularly true if the variance for the null hypothesis was very close to the alternative hypothesis variance.

Nonparametric sequential accuracy tests

Description of tests

Because differences are not always normally distributed, a nonparametric sequential accuracy test was derived (Brack and Marshall 1990; Marshall and LeMay 1990) using Wald's SPRT (1947), and a transformation of the differences to a binomial distribution. Acceptable observations are given a value of one, and are defined as observations with an absolute difference that is less than or equal to the error limit, e_0. Unacceptable observations were given a value of zero. The test statistic T_3 is:

$$T_3 = \sum_{i=1}^{n} x_i$$

where if $(|d_i| \leq e_0)$ then x_i=1 and x_i=0 otherwise. The test statistic is simply the sum of acceptable observations at any stage in the sequential sampling procedure. The proportion of acceptable observations is tested. The user of the test must specify p_0 and p_1, for the null and alternative hypotheses. The value p_0 can be interpreted as the minimum proportion of acceptable observations for model acceptance, and p_1 is the maximum proportion of acceptable observations for model rejection. Using specified α and β levels, the resulting parallel decision lines are:

$$\textit{Line } 1: \quad h_1 + s \cdot n$$
$$\textit{Line } 2: \quad h_2 + s \cdot n$$

$$h_1 = \frac{\ln\left[\frac{\beta}{1-\alpha}\right]}{\ln\left[\frac{p_1(1-p_0)}{p_0(1-p_1)}\right]}$$

$$h_2 = \frac{\ln\left[\frac{1-\beta}{\alpha}\right]}{\ln\left[\frac{p_1(1-p_0)}{p_0(1-p_1)}\right]}$$

$$s = \frac{\ln\left[\frac{1-p_0}{1-p_1}\right]}{\ln\left[\frac{p_1(1-p_0)}{p_0(1-p_1)}\right]}$$

where $h_1 > h_2$. As with the parametric test, a random observation is drawn from the application population and T_3 is calculated. If $T_3 \geq h_1 + s \cdot n$, the equation is accepted. If $T_3 \leq h_1 + s \cdot n$, the equation is rejected. Otherwise, no decision is made and sampling continues. A modified test can also be used if the mean difference is expected to be not equal to zero. In this case, the test statistic can be modified to:

$$T_4 = \sum_{i=1}^{n} x_i$$

where if $(|d_i - \bar{d}| \leq e_0)$ then x_i=1 and x_i=0 otherwise. The decision lines remain the same as for T_3.

Reliability and average sample size

The reliability of the nonparametric test was examined using normal distributions and the same non-normal distributions used to test the parametric test (Wang, LeMay, and Marshall 1995). The test was reliable (actual Type I and Type II errors were at or below the nominal values) for both the normal distributions and non-normal distributions. However, for the normal distributions, the nonparametric test resulted in an expected sample size 20 to 40 % larger than the parametric test.

Example

To illustrate the use of the sequential sampling accuracy tests, data from the province of Saskatchewan were obtained. The data contained information on the values for several thematic band measures, as well as volume per plot calculated from ground plot measurements. To begin, an equation was derived to relate the band measures to ground volume. The fitted equation was:

$$log10(\hat{Volume}) = -5.529516 + 2.601694 \cdot log10(NDVI)$$
$$MSE = 0.05884$$

where MSE is the mean squared error, an estimate of the variance of the error term of the equation; and $NDVI = (band4 - band3)/(band4 + band3)$. The errors of the equation were tested and found to be normally distributed. Since the objective was simply to illustrate the use of the sequential accuracy tests, no further description of the data or the equation will be given. This equation was then considered the existing equation. The application of this equation to another area was then of interest. For the new area, observations were taken sequentially until a decision was made to accept or reject the existing equation. If the equation was rejected, the usual action would be to continue sampling until enough data were collected to fit a new equation.
For the parametric sequential test, hypotheses were established as:

$$H0:\ \sigma^2 = 0.05884 \quad (\textit{equal to the } MSE)$$
$$H1:\ \sigma^2 = 0.23536 \quad (\textit{equal to } 4 \cdot MSE)$$

Using the $\alpha = \beta = 0.05$ levels, and $\gamma = 0.05$, the two parallel decision lines were derived by:

$$\textit{Line 1:}\quad h_1 + s \cdot n = -0.4620 + 0.10876 \cdot n$$
$$\textit{Line 2:}\quad h_2 + s \cdot n = 0.4620 + 0.10876 \cdot n$$

where

$$h_1 = \frac{2 \cdot \ln\left[\frac{0.05}{1-0.05}\right]}{1/0.05884 - 1/0.23536}$$

$$h_2 = \frac{2 \cdot \ln\left[\frac{1-0.05}{0.05}\right]}{1/0.05884 - 1/0.23536}$$

$$s = \frac{\ln[0.9509^2 / 0.4754^2]}{1/0.05884 - 1/0.23536}$$

$$e_0 = \sqrt{0.05884} \cdot 1.96 = 0.4754$$

$$e_1 = \sqrt{0.23536} \cdot 1.96 = 0.9509$$

A random observation was then taken from the application population, and T_1 was calculated. The process was repeated, until a decision was made to accept the equation (i.e., accept *H0*) after 6 observations (Figure 1). Because the equation could be biased for the new population, the parametric test with correction for bias was also used. Using T_2 and *n-1* for the decision lines, the decision was made to accept the equation after 7 observations (Figure 2).

For the nonparametric test, the hypotheses were designed to be compatible with those used for the parametric test. The criterion used for the parametric test was that if at least 95 % of the absolute differences are less than or equal to the error limit, the equation was acceptable. For the nonparametric test, the equivalent criterion was that *p0*=0.95, and the error used was 0.475. The value for p1 was set to 0.67, to correspond to the alternative hypothesis of the parametric test (s12 was four times s02). The test statistic was then calculated by:

$$T_3 = \sum_{i=1}^{n} x_i$$

where if $(|d_i| \leq 0.4754)$ then x_i=1 and x_i=0 otherwise. The decision lines were then calculated as:

Line 1: $h_1 + s \cdot n = 1.3167 + 0.8439 \cdot n$

Line 2: $h_2 + s \cdot n = -1.3167 + 0.8439 \cdot n$

$$h_1 = \frac{\ln\left[\frac{0.05}{1-0.95}\right]}{\ln\left[\frac{0.67(1-0.95)}{0.95(1-0.67)}\right]}$$

$$h_2 = \frac{\ln\left[\frac{1-0.05}{0.05}\right]}{\ln\left[\frac{0.67(1-0.95)}{0.95(1-0.67)}\right]}$$

$$s = \frac{\ln\left[\frac{1-0.95}{1-0.67}\right]}{\ln\left[\frac{0.67(1-0.95)}{0.95(1-0.67)}\right]}$$

A random observation was then taken from the application population, and T_3 was calculated. The process was repeated, until a decision was made to accept the equation (i.e., accept *H*0) after 9 observations (Figure 3). The nonparametric test with correction for bias (T_4) was also used; the decision was the same.

The example illustrates the use of the test procedures. Since the differences were normally distributed, either test is reliable. However, the parametric test accepted the equation after fewer observations were taken.

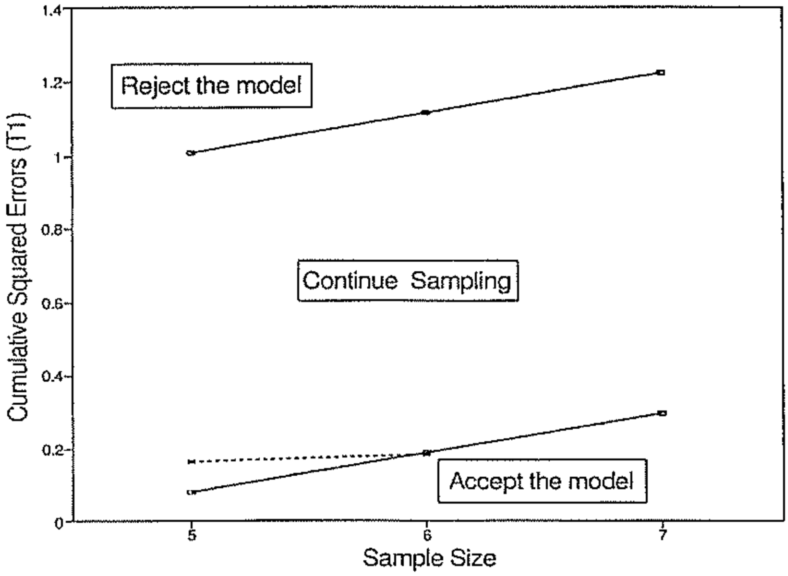

Figure 1. Parametric accuracy test.

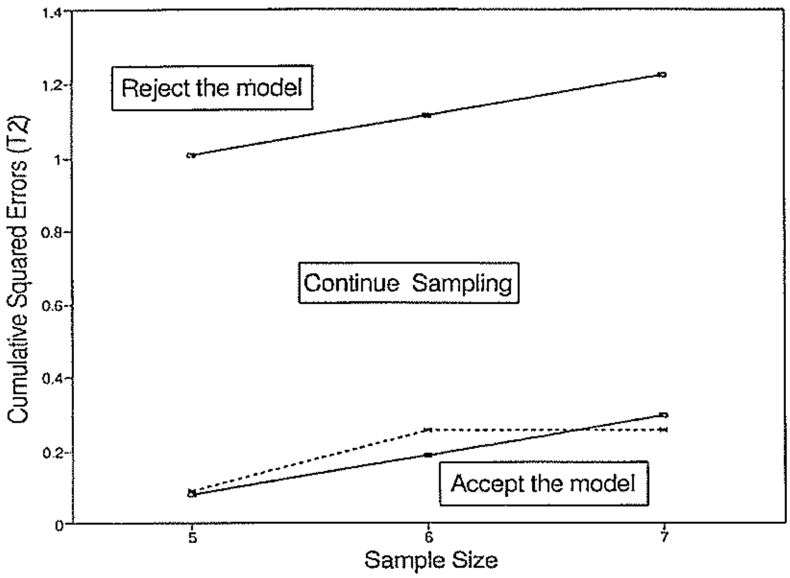

Figure 2. Parametric accuracy test after bias correction.

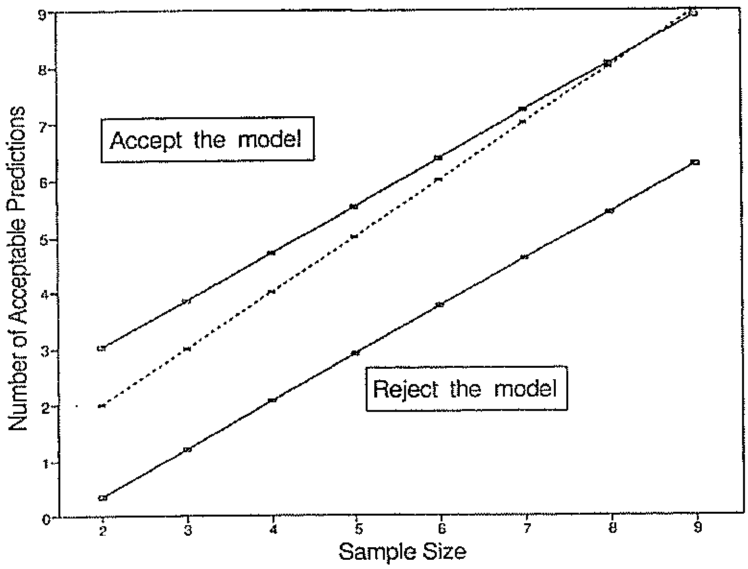

Figure 3. Nonparametric Accuracy Test.

Conclusions

Before applying an existing equation to a new population or to a subpopulation, the accuracy should be evaluated. Variable sample size procedures can be used to test the applicability with a reduction in cost over fixed sample size procedures. For normally distributed differences, the parametric sequential accuracy test is recommended over the nonparametric test because of the lower expected sampling cost. However, the nonparametric test is reliable for both normal and non-normal distributions.

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Data Collection in Tropical Forests

Moderator: M. Ellatifi, Yemen

PRODUCTIVITY MODEL FOR TRADITIONAL AGROFORESTRY SYSTEMS OF HIMACHAL HIMALAYA

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Abstract

Traditional agroforestry systems of Himachal Himalaya in general give a picture of multipurpose land use systems. The obvious approach for the evaluation of traditional systems should be to express the productivity of different components in measureable, quantitative and meaningful terms. The use of mathematical statistical models for evaluation of agroforestry systems has increased markedly, however until now, their use in completely describing these systems have many limitations like normal distributions, sample size structural and functional variations, etc.

In the present paper, three most predominant agroforestry systems have been evaluated through using resource inventory models and described through resource flow between various parts and/or components of the system. These inventory flow diagram (IFD) models have rarely been applied to the traditional system. IFD models thus generated, summed up scores of each major factor - biological productivity, soil, economic, social and other criteria, giving relative weight to each subfactor and arriving at a percent index.

Through these models definite criteria is developed that can be employed in evaluation and can convincingly assess the merits and advantages of one agroforestry system in comparison to another agroforestry system or other land use system. If such an IFD model framework is conceived at the project planning stage, it will enable the researchers to assess the relative advantages of various technology innovations at successive stages.

Key words: Productivity, traditional, agroforestry, inventory model

Introduction

The traditional agroforestry systems have not been sufficiently documented. Their potential has remained vastly underexploited and they have not been extrapolated for meeting the increasing demands of a village ecosystem. Considering the potentials of agroforestry and the lack of quantitative methods to compare and evaluate agroforestry systems, it is important that widely adaptable methodologies are developed for evaluating such systems. Evidence in the literature shows that this idea has caught the attention of some researchers. Tabora (1991) used the "Agroecosystem Analysis Framework", originally proposed by Conway (1986) to analyze and evaluate four agroforestry systems in the Philippines: criteria like social relevance (suitability), profitability, balance (equilibrium), versatility and creativity, and longevity and reliability. The methodologies used for quantifying these parameters however, are unclear; they need to be refined considerably before they can be widely adopted. However, Fujisaka and Wollenberg (1991) examined interactive changes and adaptation of human and natural systems in two pioneer forest settlements and compared them in terms of "productivity, stability, equitability, and sustainability". These have two shortcomings: 1) the methodologies are not quantitatively objective; therefore, the procedures cannot be extrapolated to other locations, resulting in relevance only to the specific location of the study, and 2) the approach is excessively oriented to social science parameters with very limited biophysical evaluation.

Nair and Dagar (1991) brought out a detailed procedural approach to develop a comprehensive methodology for evaluating agroforestry systems. Under the present investigation, the three most extensively practiced traditional agroforestry systems, i.e., Silviagriculture, Hortiagriculture and Hortiagrisilvi systems were studied in the mid hills of Himachal Himalaya, (Atul *et al* 1990) with the following objectives:

1. to develop productivity model for evaluating the traditional agroforestry systems.
2. to study the resource allocation in different entities of the systems.
3. to determine the contribution of each components of the agroforestry entities.

Material and methods

The present study was carried out in village "Kailar" (for details refer Atul *et al* 1994). Performance of various agroforestry structural entities - agriculture, horticulture and silviculture was studied in terms of biomass and nutrient dynamics. However, the present text deals with productivity aspect only. Biomass studies were conducted in two parts, i.e., above-ground and under-ground plant biomass.

Biomass and productivity of crops and weeds determined by harvest method. Plants were harvested at their peak biomass stage for *Kharif* (July-August, 1986) and *Rabi* (February-March, 1987) seasons, respectively. The productivity and the economic yield (grain/fruit) of each crop was determined through permanent quadrates in all the three systems. The productivity values, thus obtained, were converted to biomass on unit basis (per hectare) with the help of phytosociological data (Atul *et al* 1990).

For tree biomass estimation, all the trees were numbered in the randomly selected fields of the three systems. As the systems under study were traditional ones, the diversity in age distribution of tree species was worked out on the basis of their collar diameter frequency classification. The collar diameter of the trees in the system under study ranged between 6-120 cm, which were classified into six diameter classes at an interval of 20 cm each. To nullify the effect of uneven distribution of trees on biomass studies, 10 trees of each species were randomly selected from all the numbered trees using random number table.

Biomass estimation through harvest methodology was not followed in case of silvicultural and horticultural trees, keeping in view the ecological and economical constraints. In silvicultural trees, which normally have straight boles, diameter at breast height (DBH) and height of trees have been used to estimate the volume. However, this technique could not be followed in the present study as the boles were having deformed structures due to extensive branching and regular lopping practice in case of silvicultural trees and periodic pruning in case of horticultural trees.

Therefore, the "compartment" or "segment" approach has been followed in the present study. In order to estimate the annual productivity, the boles and the first order branches of the tree were divided into segments ranging in length from 0.6m (horticultural trees) to 1.2m (silvicultural trees) and were marked with paint. Initial volume of each segment was calculated using different formulae, depending upon the shape of the segment (Punam 1989) and annual increment was estimated. This increment was termed as annual productivity increment of each segment. Volumes of all the segments were pooled to determine the total annual volume of a tree. For specific density determination, wood samples were taken from each species with the help of a Pressler borer. For total biomass estimation, the volume of each tree was multiplied with its corresponding specific density value. A standard regression equation for estimating the standing biomass of a tree was worked out by using the relationship between collar diameter (x) and volume (y) of the tree. The significance of the relationship was also tested statistically (Punam 1989).

Branch biomass of each tree species was determined by the harvest method. The current twigs produced during the year were categorized into six diameter classes ranging from 0-1 cm, 1-2 cm, 2-3 cm, 3-4 cm, 4-5 cm and more than 5 cm (which were observed only in horticultural trees). Ten branches of each diameter class were harvested. The fresh weight of branches and leaves was taken in the field itself. These branches were thoroughly mixed, numbered and then 30 branches were randomly selected (with the help of random number table) for oven drying at 80° C for 48 hours. Thus, above-ground dry weight was calculated by multiplying the number of branches of each tree (separated into different diameter classes) with the dry weight of branches and leaves, respectively. However, in horticultural trees, branches more than 5 cm in diameter were also harvested. As farmers traditionally prune the branches after every two years in August, so for these branches, the calculated biomass was taken as half of the total estimated biomass.

The rate of current annual accumulation of biomass was estimated by putting the value of annual increment of diameter into the standardized regression equation. To work out the annual productivity of trees, the branch and leaf biomass production values were also added. The phytosociological data were used for determining per hectare annual productivity.

The root biomass of agricultural crops was determined by digging a 30 cm deep trench and then uprooting the plants i.e. crops and weeds, thus minimizing the root damage. The soil was washed away from roots with the help of water at normal pressure and were sun-dried. Oven drying of roots was done at 50° C for 24 h for dry weight estimation and later on the weight was converted to per hectare values. Root biomass in trees could not be determined because of non-feasibility of the destructive sampling in the farmers owned trees.

Statistical methods

A completely randomized statistical methodology was followed throughout the study and standard equations were used as and when needed to arrive at concrete results.

Results

In Himachal Himalaya, fruit trees such as apple *(Pyrys malus)*, plum *(Prunus domestica)*, apricot *(P. armeniaca)*, peach *(P. persica)*, pear *(Pyrus communis)*, almond *(Prunus amygdalus)*, walnut (*Juglans regia*), etc., are grown in temperate zone along with the agricultural crops like maize (*Zea mays*), tomato (*Lycopersicon esculentum*), beans (*Phaseolus vulgaris*), capsicum (*Capsicum frutescens*), potato (*Solanum tuberosum*), peas (*Pisum sativum*), wheat (*Triticum aestivum*), etc. Agricultural crops, raised in the interspaces of fruit trees such as citrus (*Citrus spp.*) and litchi

(*Nephelium litchi*) are common examples of agroforestry practices of the sub-tropical zone of the state. Economically important fodder and fuel trees such as Buel (*Grewia optiva*), Khirik (*Celtis australis*), Kachnar (*Bauhinia variegata*), Tooni (*Toona ciliata*), Poplar (*Populus ciliata*), Simal (*Bombax ceiba*), etc. are also integrated with agricultural crops either on the field bunds or in the field only. It has been observed that though there is a shortage of fodder and fuel wood yet the 60% of the fodder and 70% of the fuel wood requirement of the village are met from the village resources itself (Atul et al 1994).

Agroforestry practices of the Kailar village were represented by different combinations ofsilviculture, horticulture and agriculture. The fields were mostly small terraces running along the contours. Growing of trees on the terrace bunds is a traditional practice.

It was observed that *Grewia, Bauhinia, Celtis, Albizia* and *Morus* were grown for fodder, *Toona, Pistacia, Melia, Prunus* and *Bombax* were grown either for fuelwood or for timber. Field surveys indicated the farmers' inclination towards the growing of fruit trees like plum, apricot, pear, almond and peach.

Though cereal crops like maize and wheat were also cultivated by the farmers yet more emphasis was on vegetable crop production. The common seasonal vegetables cultivated were *Capsicum* and tomato in *Kharif* season and peas and cauliflower in *Rabi* season.

System I - Silviagriculture was having *Grewia* and maize, System II - Hortiagriculture - plum and *Capsicum* and System III - Hortiagrisilviculture - was having plum, *Capsicum* and *Toona*. The order of species was on the basis of their respective predominance values. These systems had a multistoreyed vegetation stratification. Perennials i.e. fruit, fodder, fuel and/or timber trees occupied the top layer followed by cereal and vegetable crops as middle layer while the weeds formed the lower most substratum.

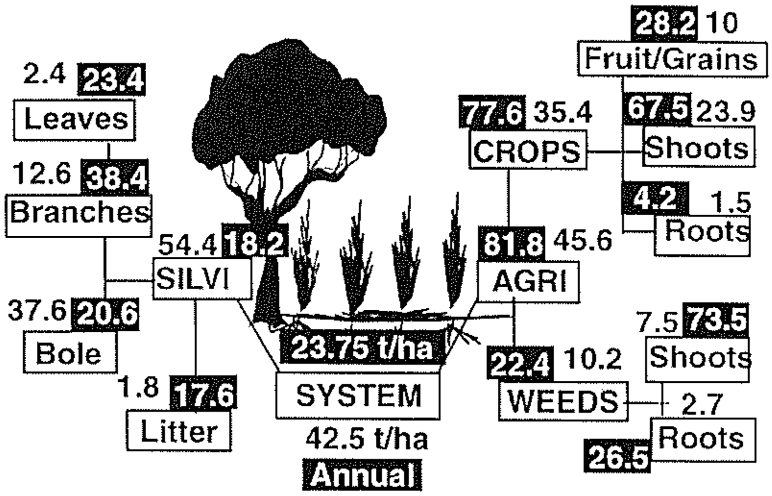

Figure 1. Productivity IFD model of silvi-agri system.

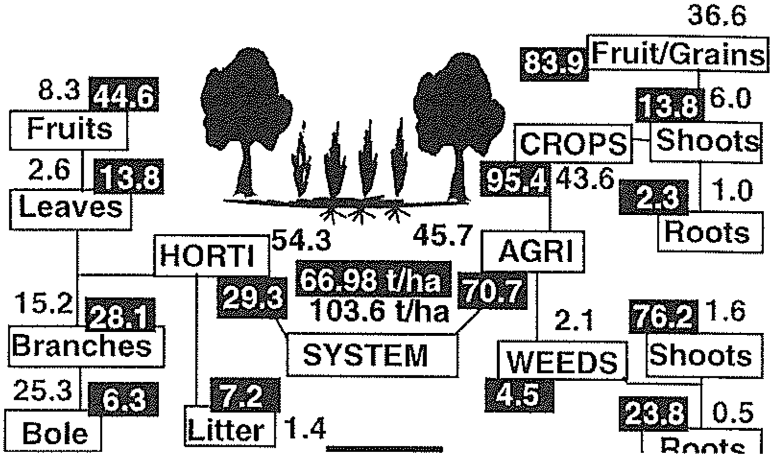

Figure 2. Productivity IFD model of horti-agri system.

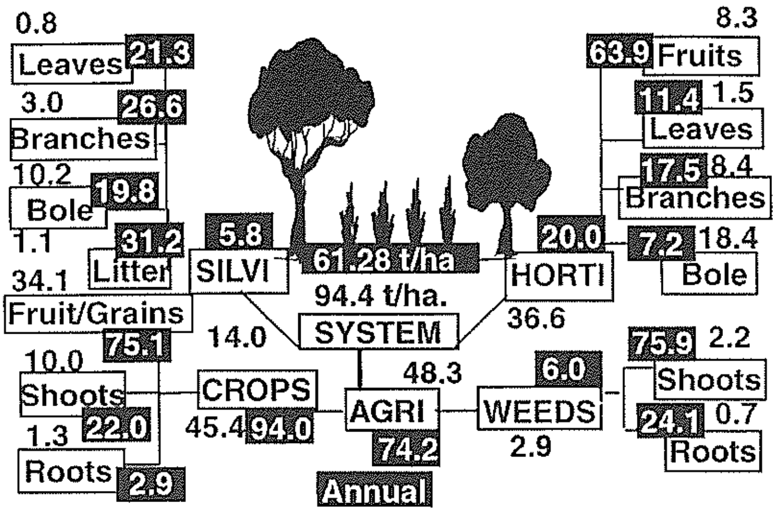

Figure 3. Productivity IFD model of silvi-agri-horti system.

The inventory was developed with respect to each entity in all the three systems i.e. for SA, HA and HAS systems and it was found that HA and HAS systems were the most productive (103.6 t /ha and 94.4t/ha) irrespective of total or annual biomass - 66.98t/ha and 61.28t/ha respectively whereas in SA system, there was significant decrease in the annual biomass accumulation.

Total biomass contribution of agricultural crops to the systems was less than 50 per cent in the three cases whereas it ranged from 51.7 to 54.4 per cent in case of trees. When this inventory was studied with respect to total biomass allocation, the key adoption factor (fruit/fodder/fuel/food) was suppressed because of structurally and functionally different entities - perennials and annuals and the effect of resource bank i.e., standing biomass was eliminated when both trees and crops were studied in terms of annual contribution. The variation in the agriculture crop productivity clearly indicates the effect of architecturally different tree neighbors. The productivity was least in HA system and maximum in SA system (SA> HAS>HA).

The specific tree productivity/adoption has played an important role in the development/evolution from tree to tree-crop system. Adoption of horticulture put forth the shift from silviculture in ancient tree system to horticulture in advanced tree-crop system. Productivity of silviculture entity in SA system (18.2%) was enhanced by introducing horticulture in HAS system to 25.8 per cent (horticulture contribution upto 20%) and finally in HA system, productivity was increased upto 29.3 per cent where silviculture was eliminated.

In an earlier study (Atul *et al* 1995) it has been reported that the species contribution towards the overall biomass is system specific. In the bole biomass of SA system, the contribution of *Morus* was minimum, (68%), while that of *Celtis* was maximum (88.42%). But their branches exhibited a reverse relationship, i.e., 29.53 and 8.33 per cent, respectively (fig. 1). Contribution of leaf biomass was minimum (2.45%) in the case of *Morus* and maximum (10.39%) in the case of *Toona*. In HA system, though plum recorded maximum (55.87%) bole biomass, yet its fruit biomass production was minimum (16.81%). This relationship was, however, reversed in case of pear, which produced the lowest bole biomass and the highest branch and fruit biomass (for details see Atul *et al* 1995). The branch component of apricot was the lowest, while its leaf component contributed the highest percentage. In HAS system, contrary to the sequential order of horticultural and silvicultural entities, the bole (38.33%) and branches (12.76%) of apricot and leaves (2.55%) of almond contributed least, whereas the maximum contributions (79.65%, 37.84% and 13.63%) to the system were made through the bole, branches and leaves of Morus, Bombax and Grewia, respectively.

Annual Productivity:

(a) Trees: For a proper understanding of the role played by each species in the three systems, their annual biomass increment/productivity was worked out. In general fruit trees had more annual branches and leaves biomass accumulation than the silvicultural trees. But fodder trees had more annual productivity, in terms of bole, branches and leaves, than the timber/fuelwood trees. The variation in annual mean biomass accumulation was maximum in bole, branches, leaves and fruits of plum, whereas it was minimum in bole and branches of Morus and leaves of Albizia.

In general, the annual productivity differed significantly in different components of a species within a system. In SA system, fodder trees like *Grewia*, *Bauhinia* and *Celtis* recorded significantly higher annual biomass accumulation in bole and branches than that of *Morus*. However, the annual leaf biomass production was not significant despite its variation from 0.89 kg/ha in *Morus* to 3.58 kg/ha in *Grewia*. In case of timber/fuelwood trees, significant differences in the bole, branches and leafbiomass of *Toona* were observed. *Pistacia* accumulated significantly, more biomass in the branches than *Toona* and *Melia*.

In HA system, annual bole biomass accumulation was significantly more in peach than in other fruit trees. The branches and leaves of apricot accounted for significantly higher biomass production than those of pear and almond. However, a peculiar type of relationship existed in HAS system. Fruit, fodder, fuelwood and timber tree components were either statistically at par or highly significant from each other. Apricot had significantly higher branch biomass than the other fruit trees (plum, pear and almond), which were statistically at par among themselves. This clearly demonstrated the varying performance of an individual species in structurally stratified environment of the three systems.

Inter-system species performance was also studied. This study naturally applied to the species occurring in more than one system. Among the silvicultural trees, *Celtis* raised in SA system accumulated significantly more biomass in all its components than when raised in HAS system. The other species behaved statistically alike under the two systems, excepting *Morus* which produced significantly more branch biomass in HAS system. Accumulation of biomass in the boles of fruit trees was independent of the two systems in which they were occurring and the same position held good in respect of annually accumulated biomass in leaves and fruits of plum, pear and almond, albeit biomass in *Prunus* branches, leaves and fruits was significantly reduced in HAS system.

(b) Agriculture: Vegetable crops of Kharif season were, in general, higher yielding than cereal crops irrespective of their root, shoot and fruit/grain productivity. In terms of annual biomass, the vegetable crops yielded considerably more than maize - 1.6 times of root biomass, 2.0 times of shoot biomass and 19.9 times of economic yield. However, on the basis of their annual productive values, the cereal crops were higher productive entities than weeds. But biomass productivity of weeds was highly variable as evidence from their higher coefficient of variance values.

Annual productivity of root and shoot components of weeds in the three systems indicated that *E. crusgalli, G. parviflora and D. sanguinalis* were lower yielding in HAS system than ill SA system. However, no specific trend was observed in *C. benghalensis, E. colonum and C. rotundus.* A highly significant ($P < 0.01$) difference was observed in both vegetable and cereal crops when their performance was compared in HA, HAS and/or SA systems. However, root biomass of most of the weeds under the three systems differed significantly except in case of *C. benghalensis*, which had significantly lower root yield in HAS system as compared to SA system. But annual shoot productivity of *C. benghalensis* and *C. rotundus* did not differ significantly between the three systems.

Discussion

The management and improvement of agroforestry systems should be based on a satisfactory understanding of their structure and functions. This is a complex task since these systems are complicated and a great many aspects must be taken into consideration.

To facilitate this task, the use of models for organic matter and nutrient cycles have been proposed. The models provide a simplified representation of the reality, but demonstrate the most conspicuous aspects the system through their complete, integral and holistic character. Much emphasis has been placed on developing modeling techniques in the last few years; however, until now, their use for partially or completely describing agroforestry systems has been limited (Alpizar *et al* 1986).

The synchronization of fruit trees with agriculture under agroforestry clearly indicated that the farmers of this Himalayan region had dual benefits i.e., they were ensured not only the economic gains (CPCRI 1979; Nair 1979) from trees but also tended to enjoy insurance against unfavorable conditions for agriculture crops. In addition, it can also be inferred that the farmer is not unaware of the fact that this cropping system has the potential of supplying more basic system needs than pure cropping (Budowski 1983).

There are four major factors which play an important role in working out the potential of an agroforestry system (Nair 1993) i.e., biological productivity, soil related, economic and social. These factors contribute in the system to the tune of 30, 25, 25 and 20 percent respectively. Biological productivity can contribute even upto 50 per cent of the total potential. The study of traditional agroecosystem (Atul *et al* 1994) have demonstrated that the village ecosystem is deficient in fodder supply. Hence, the farmer was inclined to grow more fodder trees than timber/ fuelwood trees emphasizing the importance of need for a particular species adoption in the system. This not only ensured increased productivity but also assured maintenance of ecological balance. Predominance of plum, *Grewia* and *Toona* trees supported the adoption of economically and nutritively superior species, which is not a new concept, but has been in practice since times immemorial. This supports the importance of social factor in agroforestry practices.

Due to increasing population and economic pressures, the shift has been towards horticulture which gives more economical returns for less resources.

Hence, in the adoption of HA system the economic factor played an important role in addition to the social factor i.e., most of the people having family labor problem adopt the horticulture system. On this basis, the present agroforestry systems can be reviewed -silviagriculture (SA) system as a primitive agroforestry system and the hortiagriculture (HA) an advanced agroforestry system which ultimately will lead to orchard and hortiagrisilviculture (HAS) system as a transitory system ascending towards horticulture. However, HAS system is the most sustainable and ecologically viable system because it contributes to reduce the pressure of 0.2 million m^3 wood which is axed in Himachal Himalaya for packing of apple and other stone fruits and fresh vegetables (Woodwell *et al* 1975).

According to Nair (1993) the biological productivity consists of three sub-factors i.e., grain crops, tree fodder and wood production. However, in the present study, it was observed that horticultural tree species accumulated more biomass than silvicultural trees. Therefore, instead of three, four sub-factors should be quantified to determine total biological productivity of a system. Among the silvicultural trees, fodder tree species contributed more in SA and timber/fuelwood tree species in HAS system. Tree density per unit area tended to monitor this behavior. Hence, in addition to the overall structure (standing biomass) studies, the annual productivity in trees should also be studied, not withstanding that variable biomass accumulation in respective tree components is a function of the tree habit. This concept is further supported by the higher bole biomass in timber trees and higher productivity values of branches and leaves in fodder and fruit trees - as an ideal timber tree should have straight, long bole and good fodder as well as fruit trees should have short boles laden with more fruit and leaf bearing branches.

Annual productivity or organic matter increment in bole, branches and leaves of fodder trees is more than that of timber/fuelwood trees. The reason for such a behavior being the traditional practice of extensive lopping - virtually no leaves and branches are left on the tree trunk making it impracticable for the tree to activate its regeneration potential at a faster rate. This is an other important social factor in traditional agroforestry systems.

Interaction between neighboring plants need not always be competitive. Plants may complement each other in sharing of resources for ensuring their complete utilization. In *Rabi* season both crops and weeds were independent of the neighboring trees. This may be the resultant of their aggressive/hardy nature, i.e., their inbuilt capability to withstand a wider amplitude of overall environmental and neighboring micro-environmental variations. However, the extent of plant interaction also tends to regulate the crop performance (Connor 1983). *C. frutescens* in association with HAS components projected significantly higher yield than when grown in HA system. Presence of thin crowned (silvicultural) trees might have reduced the shading effect (Vergara 1982b) of the neighboring fruit trees on the crop. Though wheat is not a shade loving crop yet it is grown in *Rabi* season in association with silvicultural trees. This may be due to the fact that in *Rabi* season tree competition is virtually negligible because of (a) dormant phase of trees and (b) the almost complete leaflessness of fodder trees owing to their extensive lopping during this season.

The results have clearly demonstrated that in *Kharif* season crops can be successfully grown in association with horticultural trees. The weed frequency in the system is considerably reduced probably because of adverse shading effect of the trees as well as crops. The system naturally commends itself for adoption.

Though agroforestry is coming up as the best land management system yet it is not likely to be accepted by all particularly the marginal and small land holders, unless it is extensively/thoroughly proved superior to other forms of land use not only on biological grounds but also on ecological and economical considerations. It has been reported that the marginal and submarginal lands are usually uneconomical and the production potential is only 300 g/m^2/yr whereas the modified system of growing of *Digitaria decumbense* instead of *Heteropogon contortus* and *Chrysopogon fulvus* with *Crewia, Bauhinia* or *Celtis* has increased the yield to 2100, 2400, 2450 g/m^2/yr respectively (Sharma *et al* 1988). The replication of such systems will not only contribute to meet the fodder shortage but will also help in meeting the 2.3 million tons of fuelwood requirement of the state. It has also been stated that the natural grasslands produce only 0.75 t/ha - 0.9 t/ha, whereas the improved grasslands contribute to 3 - 10 t/ha. If a village ecosystem is experiencing a shortage of fuelwood and fodder both, the adoption of two tier silvipastoral system will produce 12 - 25 t/ha and if fuelwood shortage alone, the energy plantation will yield 30 - 70 t/ha. Keeping in view the social constraints the adoption of horticulture should always be advocated in terms of HAS system being the socially, biologically, economically and ecologically sustainable.

The percentage indices (IFD model) obtained for different systems indicate the relative advantages of one system in terms of different products and services, in comparison to other systems. The analysis will also bring out the important topics on which research and other efforts should be focused to improve the output of the desired product or service.

Obviously, a comprehensive analysis of this nature requires considerable skill and knowledge of individual systems, farmers' preferences and perceptions and the contexts in which they occur. If such a broad analytical framework is conceived at the project planning stage, it will enable the researchers to assess the relative advantages of various technology innovations at successive stages during the life of the project. Similar analyses conducted uniformly in different ecological regions could be compared and used to prepare matrices of agroforestry systems in different agroecological regions.

IFD Model sum up the scores for each major factor (giving relative weight for each subfactor to the total and the whole factor) and arrive at a percentage index. This index indicates the relative merit of the system being evaluated in comparison to the system against which it is compared, for fulfilling the perceived goals (objectives and outputs).

Hence, it is necessary that using this package of productivity IFD model technology, a net work study in different villages and agroclimatic zones of Himalayas should be initiated. The study of traditional as well as new agroforestry systems will help in identifying the most sustainable practice and this replicated at village level will go a long way in protection, conservation and restoration of the global ecosystem.

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MULTI-PHASE SAMPLING SCHEMES FOR EXTENSIVE FOREST SURVEYS IN TROPICAL FORESTS

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Abstract

The need for information on forest resources in the Tropics is manifold and ranges from forest management planning to monitoring of sustainability according to Agenda 21. The scale of the assessments varies accordingly from inventories of domains to multi-national assessments such as the FAO Forest Resources Assessment 1990. Thus forest assessments in tropical forests cover a wide range of objectives and require appropriate sampling designs.

Surveys in tropical forests based solely on terrestrial measurements are only in exceptional cases cost-efficient. The need for inventories that combine information from various data sources such as ground assessments, aerial photography, and satellite data is widely accepted due to the poor accessibility and the heterogeneous structure of tropical forests. However, there exists a gap between combined inventory methods described in the literature and those actually applied. This paper attempts to cast some light on this gap. Sampling designs for multi-phase forest surveys are described and discussed against the background of realistic inventory objectives.

Key words: Inventory, multi-phase sampling, tropical forests

Introduction

The need for information on forest resources in the tropics is manifold and ranges from forest management-planning to monitoring sustainability according to Agenda 21. The scale of the assessments varies accordingly from inventories of domains to multi-national assessments such as the FAO Forest Resources

Assessment 1990. Thus, forest assessments in tropical forests cover a wide range of objectives and require appropriate sampling designs.

Surveys in tropical forests based solely on terrestrial measurements are rarely cost-efficient. Due to the poor accessibility and the heterogeneous structure of tropical forests the need for inventories that combine information from various data sources such as ground assessments, aerial photography, and satellite data is widely accepted. However, a gap exists between combined inventory methods described in the literature and those actually applied. This paper attempts to cast some light on this gap. Sampling designs for multi-phase forest surveys are described and discussed against the background of realistic inventory objectives.

Sampling designs

Sampling designs for tropical forests should increase cost-efficiency through the application of multi-phase sampling techniques and make it possible to monitor changes on successive occasions. Although both requirements have been described in detail, methods for combining them to create multi-phase sampling designs for successive occasions are rarely found in the literature. Furthermore, most designs focus on the assessment of variables on an interval or absolute scale, such as the number of stems or timber volume, but fail when applied to variables on a nominal or ordinal scale. Future objectives such as information on biodiversity or non-timber forest functions require the assessment and analysis of attributes on a non-metrical scale and thus a generalization of existing sampling designs. This section reviews well-known sampling designs for multi-phase surveys and sampling on successive occasions and outlines a general concept for combining of both sampling strategies.

Multiphase sampling designs

Multi-phase sampling designs include information from different assessment levels. The data collected from the n-1 phases serve as auxiliary variables, while the variables of interest are derived from data from the lowest (n_{th}) level. Remote-sensing techniques are the ideal solution for data assessment of the n-1 phases as they reduce the assessment cost for auxiliary variables considerably compared to the assessment cost of the variable of interest. The sample size is highest in the first phase and decreases from phase to phase. There are two types of multi-phase sampling designs which can be applied to combined forest surveys: multi-phase sampling with regression estimators (MSR) and multi-phase sampling for stratification (MSS).

Multi-phase sampling with regression estimators

In MSR the relationship between the auxiliary variables and the variables of interest is described by means of regression functions (Cochran 1977, Bowden et al. 1979, Johnston 1982). This design has proved cost-efficient for some timber surveys in temperate forests (Zobeiry 1972, Tandon 1974, Chen 1979). The efficiency depends on the R^2-values of the regression functions. In temperate forest - which are much more homogeneous than tropical forests - R^2-values obtained for timber volume normally range between 0.2 and 0.4. In some exceptional cases higher R^2-values have been reported. However, many studies that yielded high R^2-values were based on homogeneous test sites such as thinned pine stands in a small test site in northern Germany (Chen 1979), or even-aged spruce stands in the Black Forest (Tandon 1974). Sometimes extremely high R^2-values could be obtained, because the assumptions of regression analysis were broken, transformations were applied that forced most of the observations in the origin, regression through the origin has been applied, or outliers were remeasured or removed.

MSR has some major disadvantages which limit its application in forest surveys. If results have to be broken down into subunits and presented in tables - as commonly the case in forest surveys, the independent cell values will not add up to the row and column sums of the table. Such non-additive tables tend not to be accepted as survey results. The number of regression functions needed for the analysis can be extremely high. A regression estimate not only has to be provided for each cell value, but each attribute (volume, number of stems, basal area, timber assortments, etc.) requires its own set of regression functions as well. In a timber survey this easily leads to a multitude of regression analysis and aggravates the inventory analyses.

As auxiliary variables, attributes have to be measured in aerial photographs. Crown diameter, tree height or number of stems are widely used for volume estimation. None of these variables can be recommended if forests are closed with more than one storey and interpenetrating crowns - as typical for tropical forests.

In the special case of volume estimation the variable of interest is not directly assessed but derived via (single tree) volume functions. These functions are subject to prediction errors, which are not taken into account when sampling errors are calculated. If aerial volume functions are applied to predict the volume observed on photo plots another source of prediction errors is added. Gertner and Köhl (1992) incorporated different error sources in an error budget and showed the effect of non-sampling errors on the overall error for the one-phase situation. Their findings can be to applied to MSR and indicate that an unrealistically high precision is feigned if only sampling errors are presented.

If categorical data have to be analyzed then classical regression techniques cannot be applied. Because many of the results necessary in a forest survey are categorical, MSR is only of limited use and is by no means a tool for general use. This holds especially true for non-timber and multi-purpose surveys.

Valuating the advantages and disadvantages of MSR reveals that this sampling design can be recommended only in very rare cases for the application in tropical forest surveys.

Multi-phase sampling for stratification

In MSS the auxiliary variable does not depend on measurements but is purely an indicator variable showing the stratum to which the variable of interest is to be allocated (Cochran 1977, Bowden et al. 1979, Johnston 1982). The major difference of stratified sampling is that strata sizes are not known but estimated by samples in each of the n-1 phases. Variables of interest assessed in the n-th phase - usually on field plots - are weighted according to the estimation of strata sizes. The estimated strata sizes form the basis for the estimation of total values and their respective sampling errors. This concept adds no additional prediction error components to the overall errors. Incorrect assigned strata result in a higher variance but does not cause bias. Data analysis is simplified considerably, because no regression estimates are applied, the concept can be used for metrical and categorical data and because tables obtained by MSS are additive.

Even if in some rare cases MSS happens to be less efficient than MSR, MSS remains the first choice for most practical survey applications. Köhl and Kushwaha (1994) applied a four-phase sampling method for assessing stand volume using Landsat-TM-data, aerial photography and field assessments.

Sampling on successive occasions

In forest surveys, sampling on successive occasions is commonly based on two sampling methods: Continuous Forest Inventory (CFI) or Sampling with Partial Replacement (SPR). Other sampling procedures for monitoring purposes have been described but are in most cases derivatives of either CFI or SPR (Köhl 1990).

Continuous Forest Inventory (CFI)

CFI uses a set of permanent sample plots which are established at the first occasion and remeasured at each successive occasion. CFI was introduced into forestry by Stott (1947).CFI plots are selected either randomly or systematically to represent the entire forest population. Plots are monumented so that they can be measured on future occasions. The spatial position of each tree in a plot should be recorded to allow analysis based on paired observations of trees. Estimates are easily obtained with CFI and are particularly good for change estimation. The estimation procedures are simple and results are intuitively understood. Additive tables are obtained where independent estimates of cell values sum up to the row and column totals. The estimation procedures remain clear even for more than two occasions. A disadvantage of CFI is the dependency on the permanent plots. Because plots in distinct strata or regions may be lost, samples may not be representative over time, or the number of sample plots may be too low for some units of reference.

Sampling with Partial Replacement (SPR)

SPR was introduced into forestry by Ware and Cunia (1962) based on former work by Patterson (1950). On the first occasion, assessment and estimation procedures are the same as with CFI. On the second occasion only a portion of the plots established on the first occasion are remeasured and a set of new plots is added. The remeasured plots are used to develop regression relationships in order to update all unremeasured plots. A second estimator is based on the new plots. Both estimates are combined and result in more precise estimates of current values than does CFI (Scott 1984). Cunia and Chevrou (1969) extended SPR to multiple occasions and Newton, Cunia and Bickford (1974) extended it to the multivariate case, but problems emerged due to the awkward estimation procedures.

One advantage of SPR is that it reduces the risk of obtaining a poorly distributed sample. New sample plots are added and help make a sample more representative if the old plots were poorly distributed to begin with or if they become poorly distributed. The dependence on maintaining the permanent plots is less than with CFI. SPR also offers the opportunity to place sample plots in new areas where no permanent plots were initially established. A second advantage is that SPR is simultaneously cost effective for estimates of current values and net change in those values. Finally, SPR is very flexible. The emphasis can be altered between the estimation of current values and change detection by changing the proportion of new and remeasured plots. The estimation of current values can be improved by adding new plots; remeasuring more of the permanent plots can improve the estimation of change.

Scott (1986) described many of the problems encountered. The first disadvantage is the complexity of the design. The number of plot types increases geometrically as the number of occasions increases. With two occasions, sample sizes for three different types of plots (unremeasured, remeasured, and new) have to be determined. With three occasions, the number of plot types increases to seven.

A second disadvantage is the complex estimation procedures. The first step in the analysis is to develop regression estimates. The regression equations must be carefully monitored. When stratification is used the sample sizes are often too small to develop reliable regression coefficients for individual strata. Often the strata must be collapsed as the number of plots in the strata is too small to reliably estimate regression coefficients. The estimation procedures become very unwieldy for more than two occasions. Scott and Köhl (1994) give estimators for SPR and stratification and for up to three occasions and show their complexity. It is difficult to apply such a complex procedures in practical applications.

These estimators can be applied to independently estimate individual row and column cells, as well as row and column totals. However, estimates developed in this way are not additive; cells will not sum to estimates of row and column totals. For statisticians, non- additive tables are acceptable, but forest resource analysts prefer to use tables that are additive.

Different methods have been described to handle the problem of table cells that do not add to row and column totals. However, in forest-survey reports more than one table is presented. Additivity is required not only within tables but between tables as well.

Experience has been gained with SPR from the 1960's (Bickford et al. 1963) through to the present. However, there are only a few practical applications of SPR for more than two occasions. The tendency is to abandon SPR and move back to CFI or to other techniques like updating techniques based on growth-projection models (Hahn and Hansen 1983).

Multiphase sampling designs for successive occasions

The two sampling strategies are combined in a multi-phase sampling design for successive occasions (MSS). This section discusses MSS in relation to SPR and CFI but does not discuss MSR due to the inherent difficulties in its methodology. Bickford et al. (1963) were first to describe the relationship between SPR and MSS. Köhl (1994) and Scott and Köhl (1994) discussed SPR and stratification for two phases. First, samples are selected in the n to n-1 strata and then assigned to the individual strata. The estimator is developed in five steps:

1. Update the first-occasion strata means to the second occasion using a regression estimator and then compute their means.
2. Compute the updated mean and its variance across strata.
3. Compute the strata means and their variances for the new plots.
4. Compute the updated mean and its variance across strata for the new plots.
5. Compute the combined mean of these two independent estimates and its variance by weighting them inversely to their variances.

Scott and Köhl (1994) extended the concept of SPR and stratification from two to three occasions and showed that the estimation procedures become rather awkward.

An alternative design combines CFI and MSS (Köhl, 1994). The total value of attributes like volume, growth, basal area or area of private land and its variance are calculated according to the MSS-equations. The same equations are used to calculate the total (forest) area and its variance. Values on unit area such as volume per hectare have to be calculated as ratios of means but not as means of ratio. Even if the sample size is large, unbiased results are not obtained by means of ratios. Therefore, a combined ratio estimator is proposed to come up with area related results. The variance of the combined ratio estimator incorporates the variance estimates of total values and areas based on MSS-algorithms and an additional covariance term.

If the inventory results have to be broken down into subunits, the same algorithms can be applied. It is important to realize that the categories used to form subunits for data analysis do not necessarily have to be the same categories as assessed in the strata. The strata sizes assessed in the n-1 phases are used for weighting and do not show up in the final results.

If the results are to be presented in tables, then it is necessary to choose between three different types of tables: attribute tables, area tables and ratio tables. Attribute tables incorporate estimates of sample plot attributes. These can be measurable variables such as number of stems, basal area, growing stock and increment or they can be area-related attributes such as stand type, vegetation unit or ownership. The area covered by each individual attribute is determined as well as their sum and their variance.

Attribute Tables

V	$\hat{Y}_{11}$	$\hat{Y}_{12}$	$\hat{Y}_{1-}$
$[m^3]$	$\hat{Y}_{21}$	$\hat{Y}_{22}$	$\hat{Y}_{2-}$
	$\hat{Y}_{-1}$	$\hat{Y}_{-2}$	$\hat{Y}_{tot}$
G	$\hat{Y}_{11}$	$\hat{Y}_{12}$	$\hat{Y}_{1-}$
$[m^2]$	$\hat{Y}_{21}$	$\hat{Y}_{22}$	$\hat{Y}_{2-}$
	$\hat{Y}_{-1}$	$\hat{Y}_{-2}$	$\hat{Y}_{tot}$
N	$\hat{Y}_{11}$	$\hat{Y}_{12}$	$\hat{Y}_{1-}$
[n]	$\hat{Y}_{21}$	$\hat{Y}_{22}$	$\hat{Y}_{2-}$
	$\hat{Y}_{-1}$	$\hat{Y}_{-2}$	$\hat{Y}_{tot}$
private	$\hat{Y}_{11}$	$\hat{Y}_{12}$	$\hat{Y}_{1-}$
forest	$\hat{Y}_{21}$	$\hat{Y}_{22}$	$\hat{Y}_{2-}$
[ha]	$\hat{Y}_{-1}$	$\hat{Y}_{-2}$	$\hat{Y}_{tot}$

Area Tables

A	$\hat{X}_{11}$	$\hat{X}_{12}$	$\hat{X}_{1-}$
[ha]	$\hat{X}_{21}$	$\hat{X}_{22}$	$\hat{X}_{2-}$
	$\hat{X}_{-1}$	$\hat{X}_{-2}$	$\hat{X}_{tot}$

Ratio Tables

V	$\hat{R}_{11}$	$\hat{R}_{12}$	$\hat{R}_{1-}$
$[m^3 / ha]$	$\hat{R}_{21}$	$\hat{R}_{22}$	$\hat{R}_{2-}$
	$\hat{R}_{-1}$	$\hat{R}_{-2}$	$\hat{R}_{tot}$
G	$\hat{R}_{11}$	$\hat{R}_{12}$	$\hat{R}_{1-}$
$[m^2 / ha]$	$\hat{R}_{21}$	$\hat{R}_{22}$	$\hat{R}_{2-}$
	$\hat{R}_{-1}$	$\hat{R}_{-2}$	$\hat{R}_{tot}$
N	$\hat{R}_{11}$	$\hat{R}_{12}$	$\hat{R}_{1-}$
[n / ha]	$\hat{R}_{21}$	$\hat{R}_{22}$	$\hat{R}_{2-}$
	$\hat{R}_{-1}$	$\hat{R}_{-2}$	$\hat{R}_{tot}$
private	$\hat{R}_{11}$	$\hat{R}_{12}$	$\hat{R}_{1-}$
forest	$\hat{R}_{21}$	$\hat{R}_{22}$	$\hat{R}_{2-}$
[proportion]	$\hat{R}_{-1}$	$\hat{R}_{-2}$	$\hat{R}_{tot}$

Figure 1. Tables

In area tables the total area and its variance is presented in each cell. Area tables can be used to convert the attribute tables into ratio tables, i.e. tables related to the area. The area tables only need to be derived once for all subunits and can then be used for all attribute tables with the same categories of lines and columns. Tables derived in this manner are additive for any additional attributes.

Use of remote sensing techniques

Studies concerning the mapping of forests by remote sensing techniques have been published in numerous papers. In forestry applications the verification of the results of satellite-image classifications is very often neglected and only rarely based on a sound statistical concept. Therefore, in practical applications the magic power of colored pictures often does not hold. Bodmer (1993) investigated the accuracy of forest classifications based on Landsat-TM data in a test area with patchy forest patterns. He compared the results of different classification algorithms (parallelepiped, minimum distance, and maximum likelihood) with digital ground information and introduced a hybrid classification (i.e. manual delineation of an enhanced satellite image). The accuracy ranged from 32.3% and 75.6%. Thus great care is recommended when using satellite remote-sensing techniques for forest monitoring. This holds especially true for regions where forest stands are characterized by heterogeneity and small scale variation. The up to now available resolution of 10 to 30 m is obviously too coarse to meet all objectives of a forest survey.

Special attention in the application of satellite imagery has to be paid to the mountainous regions (Itten et al. 1992). Distinct areas of valleys cannot be interpreted due to shadows. Small scale variation of forests leads to a huge amount of mixed pixels and thus renders the selection of training areas and the classification more difficult. Geometric corrections are awkward in steep terrain. In mountainous regions where differences in altitude are larger than 500 m, atmospheric corrections should be applied. Varying illumination conditions require slope-aspect corrections based on a digital terrain model (DTM) with a higher resolution than the applied satellite pixel data.

Satellite data are commonly assumed to be readily available for almost all regions of the globe. This assumption, however, is doubtful at least for the tropics, and especially for regions with tropical rain forest. The availability of cloudless satellite scenes is extremely limited by frequent cloudiness and some satellite systems only record data for certain regions upon special request. Thus, for example, to demonstrate forest-area development between 1980 and 1990 the FAO Forest Resources Assessment 1990 had to use Landsat TM scenes from the years 1977 to 1983 and 1987 to 1991 respectively. Apart from the methodological problems encountered in evaluating satellite data, the data can only lead to summary conclusions because part of the forest-area dynamic is eliminated by the different time intervals involved. Radar data appear, especially in frequently overcast areas, to be a promising aid to forest assessment. However, the path from successful application in test areas to operational use in large-scale inventories remains long.

Conclusions

Multi-phase sampling designs offer an efficient means for obtaining information on a forested area. Particularly in inaccessible regions of the tropics, they can help to significantly increase the cost-efficiency of inventories. Two important decisions need to be made during the planning phase of an inventory: selection of statistical design and selection of data sources to be used.

The statistical design must be selected out of consideration to the inventory's particular objectives. Multi-resource surveys in particular require the evaluation of a wide array of categorical variables. Hence, multi-phase sampling designs with regression estimators are unsuitable for many applications. Multi-phase sampling designs for stratification can in some cases be less cost-efficient than other design alternatives, but they provide a generally valid tool for fulfilling the inventory objectives and thus remain the first choice.

Monitoring the sustainability of multi-functional tropical forests can only be achieved through permanent inventories. Assessments, therefore, must be planned, when possible, as permanent inventories and considerations should not be limited to an initial survey and sampling on successive occasions. Many techniques which can be practically applied for surveys on two different occasions become very complex on the third or subsequent occasions and can thereby threaten the successful execution and evaluation of an inventory.

If satellite data are intended to be used in an inventory, then it is necessary from the start to carefully check the availability of the satellite data. Especially in the tropics, cloudiness can greatly limit the use of satellite data. Moreover, a concept needs to be developed for verifying the classifications through set objectives, i.e. confirmed criteria, and for determining the accuracy of the classifications.

It is often believed that a new inventory requires a completely new inventory concept involving the most recent technical advances. In reality, however, an inventory is more likely to be successful if it is founded on well-established procedures. Only if the methods used to gather information are satisfactory to all sides and only if the results of the inventory are widely accepted will the long-term success of an inventory - and hence the financial resources - be ensured.

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STATISTICAL METHOD FOR DATA COLLECTION ON WINDBREAK SPECIES IN TROPICAL YEMEN

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Abstract

Tihama Plain is a land strip of about 30 km in width along the Red Sea coast, to the west of Yemen. Its climate is of tropical nature: hot and humid. In addition, this Plain is characterized by strong winds blowing mainly from west and south-west, thus threatening the agricultural production. A series of windbreaks have been established in the area since 1988 to protect crops and animals. To determine the growth and volume of the different forestry species planted in windbreaks, as well as their ability to withstand the effect of strong winds, a statistical methodology has been set up. This methodology is based on stratified sampling. Five different strata were considered within the planted area, and samples were randomly selected from each stratum.

Key words: Windbreaks, stratified sampling, Yemen, Tihama

Introduction

Situated in the western part of the country, Tihama plain is a land strip of about 30 km in width and 500 km in length, surrounded by the Red Sea in the west, by Harad, southern Saudi-Arabia in the north and by Bab Al Mendeb in the south. It is characterized by the scarcity of natural vegetation which directly exposes it to the strong winds blowing from the west and south-west, causing sand dune encroachment and threatening human settlements, agriculture, livestock and other infrastructure.

In order to tackle this dangerous situation, the general Directorate of Forestry and Rangelands (G.D.F.R.), in close collaboration with Tihama Development Authority (T.D.A.), launched at the end of the 1980's a vast planting operation aiming mainly at:

1) Establishing a series of windbreaks around farms,
2) Fixing moving sand dunes through the establishment of dead fences in a first step, and afforestation in a second step, and
3) Creating live shelterbelts around villages and cities.

This paper deals with the first objective of this campaign. It gives the methodology we designed and implemented on the ground to determine the growth of the different forestry species planted as windbreaks on a selected farm of the area.

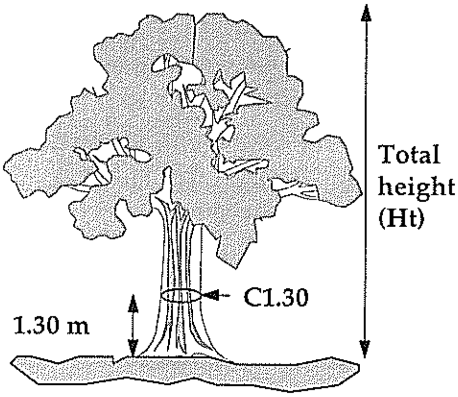


Figure 1. *Mensurations taken on sample trees (C1.30 and Ht).*

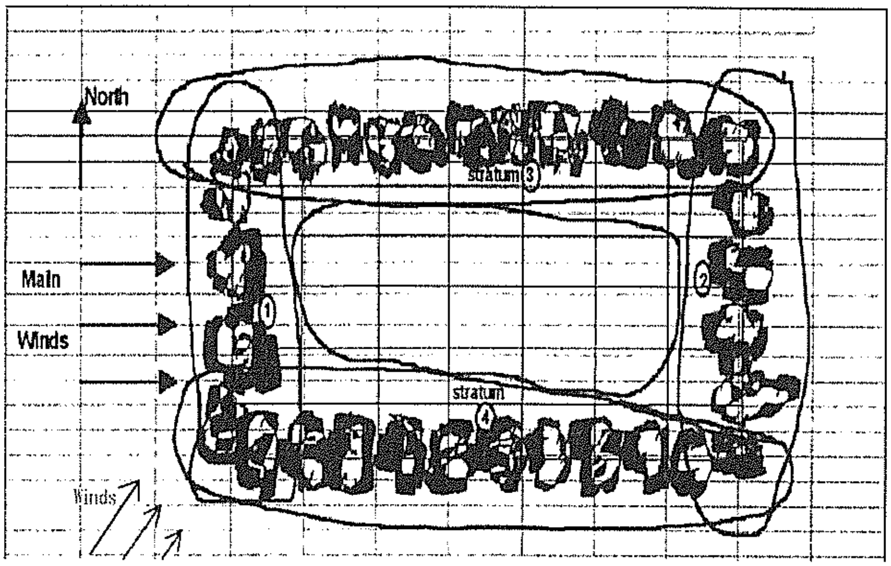


Figure 2. *Sampling design within Al Anissi Farm.*

Al Anissi Farm: Selected Area for Data Collection

Among the tens of farms which have been surrounded with one (or more) row(s) of windbreaks in Tihama plain, we chose to collect data on the growing species at Al Anissi farm for the following reasons:

1) Al Anissi farm is one of the first farms to be protected against winds (plantations started in 1988).
2) Various forestry species of different ages were used in and around the farm.
3) The farm is relatively large: its area is approximately 120 ha. It is planted with citrus fruits, mango, papaw, banana, and date-palm. It is irrigated by underground water, pumped through digged wells.

Forestry Species Used as Windbreaks

The main species used as windbreaks for this purpose were: *Azadirachta indica* (Neem), *Conocarpus lancifolius, Prosopis juliflora, P. chilensis, Leucaena leucocephala, Robinia pseudo-acacia, Albizzia lebbeck* and *Poinciana regia. Prosopis juliflora* and *P. chilensis* were planted only on the outskirts of the farm to serve at the same time as thorny fences against animals.

Data and Collection Method

For each species of interest, we know its age from its date of plantation. To know the growth diameter and heigth, we measured the circumference at breast height (c.b.h.) ($C_{1.30}$), and the total height (H_t) (Fig. 1). As the mother population was large, we opted for a sampling design in order to save time and money (Fig. 2). Four strata were distinguished, based upon the fact that the wind influence on the species is different from one windbreak to another, and from an orientation to another. Within each stratum, a random sample was selected, the size of which was chosen to be equal to 10 % of the stratum size. $C_{1.30}$ was measured with a measuring-tape, H_t was measured with a clinometer Suunto.

Main Results

The main findings by species are given in the following: (1) at the general level of the farm, (2) at the level of the rows which are perpendicular to the principal winds, and (3) at the level of the rows which are parallel to the main winds.

Table 1. General results at the whole level of the farm.

Species	*Age (yr.)*	*C1.30 (cm)*	*Ht (m)*	*Sample size (n)*
Azadirachta indica	6	42.4	9.00	175
	5	37.4	8.06	216
	4	19.8	4.84	46
	3	18.4	4.15	85
	1.5	15.2	4.14	17
Conocarpus lancifolius	6	39.3	10.57	45
	5	33.3	7.84	123
	4	25.9	6.79	39
Prosopis juliflora	5	11.7	3.87	131
Prosopis chilensis	5	11.6	4.17	90
Leucaena leucocephala	4	10.7	4.06	12
Robinia pseudo-acacia	5	10.1	4.25	4
Albizzia lebbeck	4	21.1	6.00	2
Poinciana regia	5	22.3	4.76	5

Table 2. Results at the level of the rows perpendicular to the main winds.

Species	*Age (yr.)*	*C1.30 (cm)*	*Ht (m)*	*Sample size (n)*
Azadirachta indica	6	44.4	8.94	93
	5	39.4	8.46	101
	4	20.8	5.03	25
	3	18.3	4.34	26
	1.5	15.2	4.14	17
Conocarpus lancifolius	6	39.4	10.57	45
	4	23.9	6.46	21

Table 3. Results at the level of the rows parallel to the main winds.

Species	*Age (yr.)*	*C1.30 (cm)*	*Ht (m)*	*Sample size (n)*
Azadirachta indica	6	40.2	9.06	82
	5	35.6	7.70	115
	4	18.6	4.61	21
	3	18.4	4.06	59
Conocarpus lancifolius	5	33.3	7.84	123
	4	28.3	7.18	18
Leucaena leucocephala	4	10.7	4.06	12
Robinia pseudo-acacia	5	10.1	4.25	4
Albizzia lebbeck	4	21.1	6.00	2
Poinciana regia	5	22.3	4.76	5

Table 4. Comparison between Con. lanci. & Aza. indi. growth in circumference at dbh & in height.

		Conoc. lanci.				Azadir. indica			C1-C2	Rel.	Signif.
		Age	C1/H1	S1	N1	C2/H2	S2	N2	H1-H2	var.	of diff.
Rows perpendic. to the main winds	C1.30	6	39.30	3.20	45	44.40	3.80	93	-5.10	-11%	**
		4	23.90	1.91	21	20.80	4.87	25	3.10	15%	**
	Ht	6	10.57	0.41	45	8.94	0.78	93	1.63	18%	**
		4	6.46	0.31	21	5.03	1.39	25	1.43	28%	**
Rows parallel to the main winds	C1.30	6	#	#	#	40.20	6.44	82			
		5	33.29	2.03	123	35.60	1.02	115	-2.31	-6%	**
		4	28.33	1.33	18	18.60	2.94	21	9.73	52%	**
	Ht	6	#	#	#	9.06	0.73	82			
		5	7.84	0.09	123	7.70	0.30	115	0.14	2%	**
		4	7.18	0.07	18	4.61	0.09	21	2.57	56%	**
Whole farm (All rows)	C1.30	6	39.33	3.20	45	42.43	5.03	175	-3.10	-7%	**
		5	33.29	2.03	123	37.36	1.94	216	-4.07	-11%	**
		4	25.93	1.64	39	19.80	3.99	46	6.13	31%	**
	Ht	6	10.57	0.04	45	9.00	0.76	175	1.57	17%	**
		5	7.84	0.09	123	8.06	0.31	216	-0.22	-3%	**
		4	6.79	0.20	39	4.84	0.80	46	1.95	40%	**

Legend: ** means: Difference highly significative
means: Data non-available

Table 5. Comparison between Prosopis chilensis & P. juliflora growth in circumference (C1.30) & in height (Ht).

		Prosopis chilensis			Prosopis juliflora			C1-C2	Rel.	Signif. of
	Orientation	C1/H1	S1	N1	C2/H2	S2	N2	H1-H2	Var.	the diff.
C1.30 (cm)	South	12.62	5.28	47	9.94	3.99	80	2.68	27%	**
	West	15.55	4.56	10	8.07	0.38	12	7.48	93%	**
	North	7.71	3.23	33	16.31	0.49	39	-8.60	-53%	**
	Whole farm	11.62	4.45	90	11.66	2.62	131	-0.04	0%	ns
Ht (m)	South	4.68	1.12	47	3.92	1.46	80	0.76	19%	**
	West	5.55	1.26	10	2.67	0.98	12	2.88	108%	**
	North	2.56	1.42	33	4.12	1.38	39	-1.56	-38%	**
	Whole farm	4.17	1.25	90	3.86	1.38	131	0.31	8%	ns

Analysis of the Results

For the major objective of the plantation, i.e. to break the winds, four species appear to be of special interest: *Conocarpus lancifolius*, *Azadirachta*, *Prosopis chilensis*, and *P. juliflora*. From Tables 1, 2 and 3 one can observe that the average of $C_{1.30}$ and H_t at the same age for these species are different, depending whether they were planted perpendicularly or parallelly to the main winds coming from the west.

For this analysis we compared *Conocarpus lancifolius* and *Azadirachta indica* on the one hand and *Prosopis chilensis* and *P. juliflora* on the other hand. For this purpose, we used Aspin-Welch's test (unknown and unequal variances) to test the significance of the difference of means. Table 4 gives the results of this comparison between *Conocarpus lancifolius* and *Azadirachta indica*, and Table 5 gives those for *Prosopis chilensis* and *P. juliflora*, at the 5 years of age.

From Table 4, it is obvious that, perpendicularly to the strong winds, *Conocarpus lancifolius* is superior to *Azadirachta indica*. Its average increment in height is higher, both at 4 years (+28%) and at 6 years (+18%). As for the increment in d.b.h. (or in c.b.h.), *Conocarpus lancifolius* which was superior at 4 years (+15%), is surpassed by *Azadirachta indica* at 6 years(-11%).

The lenght of the area protected by a windbreak is proportional to the total height of the windbreak itself, and when considered separately, *Conocarpus lancifolius* is a better species as a windbreak than *Azadirachta indica*. The difference in growth, both in d.b.h. (and c.b.h.) and height are highly significant (99%).

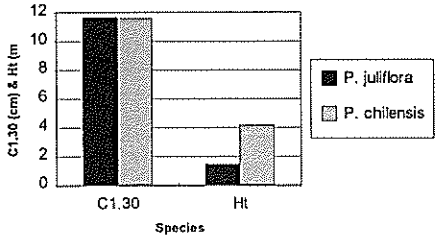
When planted in lines parallel to the main winds, *Conocarpus lancifolius* is paramount in height increment at 4 yr. (+56%), but at 5 years it becomes similar to *Azadirachta indica* (+2% only). The situation is practically the same for the increment in d.b.h. (+52%, at 4 yr., but -6%, one year later).

As for *Prosopis chilensis* and *P. juliflora* (Table 5), their comparison, at the age of 5 yr. is particularly interesting. Let us remember that these two species are planted only around the farm (windbreak and thorny fence), at the western, southern and northern sides, and that the strongest winds come firstly from the west, and secondly from the south-west. No winds of significant force come from the north (Fig. 2).

Table 5 and Fig. 3 show clearly the superiority of *Prosopis chilensis* over *P. juliflora* used as a protection against strong winds (west), both in diameter (+93%), and in height (+108%). When the wind strength decreases (South), *P. chilensis* is still paramount, but the different is smaller: +27% in d.b.h., +19% in height. In a calm or non-windy situation (North), *P. chilensis* becomes inferior to its challenger (*P. juliflora)*, both in d.b.h. (-53%), and in height (-38%). All the differences are highly significant (99%).

Concluding Comments

For the establishment of windbreaks in Tihama and in similar areas, *Conocarpus lancifolius* proved its superiority over *Azadirachta indica*, at least up to 6 years of age. Similarly, at the age of 5 years, *Prosopis chilensis* was found out to be a better windbreak than *P. juliflora*. But these conclusions could be different at an older age. Other comparisons should be undertaken at further stages to check these first findings and come out with the final conclusion.



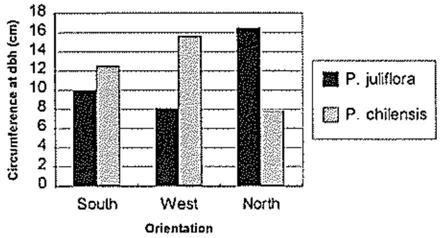


Figure 3. Growth in dbh (C1.30) and in height of Prosopis juliflora & P. chilensis (at the whole farm level) and growth in dbh (C1.30) of Prosopis juliflora & P. chilensis under different orientations (age 5 years).

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Tomorrow's Technology - Today

Moderator: D. van Hooser, USA

APPLICATIONS OF AIRBORNE VIDEOGRAPHY IN FOREST INVENTORY AND ANALYSIS AND IN ASSESSING CATASTROPHIC EVENTS

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Abstract

The United States Department of Agriculture Forest Service, Southern Research Station uses airborne videography encoded with geographic coordinates as a remote sensing tool to supplement satellite remote sensing and other research in forest inventory and analysis. Catastrophic events and cooperative projects have provided the catalyst for use of airborne videography for assessing forest inventory damage, for aiding in satellite imagery classification, and for providing aerial imagery for forest inventory research. A brief description of the airborne video system and discussion of past, current, and future forest mensuration projects that explore the many uses of airborne videography are presented in this paper.

Key words: Aiborne videography, forest inventory, catastrophic events

Introduction

The United States Department of Agriculture (USDA) Forest Service's Southern Research Station, Forest Inventory and Analysis research unit (Midsouth-FIA) performs periodic inventories of forest resources throughout the south central United States. Airborne videography (or aerial video), coupled with global positioning system (GPS) data, is a remote sensing tool being analyzed to determine new methods of supplementing these periodic field inventories. Catastrophic events and cooperative research projects have provided circumstances to exploit methods of airborne video reconnaissance. Two large-scale catastrophic events that affected the integrity of Midsouth-FIA's forest inventory were: (1) the impact of Hurricane Andrew in 1992 on the Atchafalaya River Basin of Louisiana and (2) the portion of an ice storm in 1994 that passed through northern Mississippi.

An international research venture that demonstrated the utility of georeferenced airborne videography was part of the global tropical Forest Resource Assessment 1990 Project for the Food and Agriculture Organization of the United Nations (FAO). In January 1993, airborne videography was acquired over five Landsat Thematic Mapper (TM) scenes in Mexico and used for verification of forest-cover interpretations from the TM prints (Eggen-McIntosh *et al.* 1993). The same aerial video is subsequently being used to verify digital classifications of the TM data as part of another project to map the forest distributions of Mexico. The TM classifications are then used to model the percentage of forest cover within 1-kilometer cells of Advanced Very High Resolution Radiometer (AVHRR) data.

The forest distribution mapping project has been extended from southern Mexico into Central America (Lannom 1995), but without aerial videography as a supplemental resource material. When completed, the data on forest distribution and percentage of forest cover for Mexico and Central America could be combined with similar data sets of the conterminous United States and Canada to form one contiguous map of the forest cover of North America.

Success of the airborne videography missions linked to geographic coordinates in Mexico and the states of Louisiana and Mississippi led to cooperative ventures with other agencies. These cooperative ventures are designed to train participants in the techniques involved in using airborne videography and geographic positioning. One such project was part of a long-term natural resources monitoring project throughout Senegal in west Africa being performed by the US Agency for International Development (USAID) and the US Geological Survey's Earth Resources Observation System (EROS) Data Center (EDC) (Tappan *et al.* 1994). In cooperation with Senegal's Centre de Suivi Ecologique, airborne video/GPS transects were flown systematically at 20-kilometer intervals throughout the country. The north-south flight lines were oriented perpendicular to the ecological gradient of the country as the gradient progresses from the dry Sahelian zone through the Sudanian zone to the moist sub-tropical Guinean zone (Wood *et al.*, in press).

A planning workshop recently completed in Honduras will lead to an airborne video mission, linked to proposed field plots for monitoring forest health in Honduras, and provide ancillary data for the forest distribution project in Central America. Also, a project being established in Indonesia for monitoring forest health proposes the use of airborne videography. Cloud cover situations and the immediate georeferencing techniques of GPS play an important factor in the decision to use airborne video in each of the projects. A future forest inventory project in the Georgia Piedmont of the United States will combine all of the above defined methods with data for the forest inventory field plots to enhance the field inventory and study methods of using remote sensing data for annual updates of the periodic field inventories.

Airborne video system and methods

The airborne video system at the Southern Research Station is used for acquiring vertical aerial video imagery over forest lands when rapid response is necessary or preferred. The equipment is easily transportable and can be installed in an aircraft on the same day of a video mission. The video system consists of four main parts: (1) video camera head, (2) color video monitor, (3) GPS receiver, and (4) video recording unit containing a graphics computer. The video camera head contains a 2/3-inch-format charge-coupled device (CCD) as the imaging plane (8.8 x 6.6 millimeters). Attached to the front of the camera head is an 11- to 66-millimeter zoom lens with auto-iris. Overall weight of the camera head is 1.25 kilograms. The video recording unit contains an 8-mm videocassette recorder and graphics computer for generating text onto the video imagery, such as GPS coordinates, altitude, date, and time. The recording unit also has a keyboard for entering text onto the video imagery during the mission, an input for audio, and power connections for all peripheral devices, including power for an external camcorder as a second camera.

If a camera port or small view port through the floor is not available, the camera head can be mounted underneath the airplane or helicopter. The color video monitor has two video inputs that can be used for toggling between camera views when a second camera is mounted for oblique or vertical viewing. The monitor is normally mounted on the floor in front of the video equipment operator. The video recording unit and GPS receiver are strapped together in a passenger seat or to the floor. The GPS antenna can be mounted to the top of the aircraft, inside the back window, or attached to the dash inside the front window. GPS coordinates of the video mission can also be logged for differential corrections or input to a geographic information system (GIS).

These missions are designed somewhat differently from an aerial photography mission. Where aerial photography missions are flown to acquire total coverage over a study area, aerial videography is best utilized as a sampling tool. Video flight lines are flown at a nominal spacing to provide a sufficient number of samples for the study area. A typical mission that provides high enough resolution to determine details within the canopy structure may record a 100-meter swath along the flight line transect. A single video frame at this resolution will cover 0.75 hectare.

If a wider swath is desired for broader areal ground coverage and visualization of individual tree crowns is the desired component rather than canopy structure, the swath can be increased to 250 meters. This choice will provide a single video image of approximately 5 hectares. For timber-type mapping, a video swath of 1,000 meters may be more desirable. The digitized video frame will cover approximately 75 hectares and may not provide enough resolution to discern individual tree crowns, but timber stand boundaries can be distinguished for mapping purposes.

Catastrophic events

A two-phase sampling plan was developed to allow quick assessments of catastrophic events that affect the integrity of statewide forest inventories. First, an airborne video mission is flown to obtain a sufficient sample of aerial imagery over the affected area. These video sample data and corresponding geographic coordinates are used to determine damage severity and to map the location and associated damage in a GIS. Second, the resulting assessment data are combined with the most recent data from the statewide field inventory for the study area. This technique provides an estimate of the forest resources damage, area of forest land, and forest-type groups affected by the catastrophic event. Two examples of implementing these technologies are given in the following sections.

Hurricane Andrew, Southern Louisiana-1992

Methods using airborne video sampling techniques were developed by Midsouth-FIA to assess the timber damage caused by Hurricane Andrew in Louisiana (Jacobs and Eggen-McIntosh 1993). After causing severe damage during its passage over southern Florida, Hurricane Andrew regained strength as it moved westward through the Gulf of Mexico. As the storm was being tracked across the Gulf, plans were being made to assess the inevitable timber damage that would occur when the hurricane proceeded inland. During the night of 25 August 1992, the hurricane made landfall a second time as it entered the Atchafalaya River Basin in southern Louisiana. The storm moved due north as it moved inland and soon lost strength as it entered Mississippi and turned toward the northeast.

Limits of the study area were determined according to aerial reconnaissance flights the day after the storm cleared the area. Flight lines were laid out in an east-west fashion perpendicular to the path of the storm. The airborne video mission was performed 3 days after passage of the storm, and the damage assessment was completed within 4 weeks. Field crews gathering forest damage information on the ground also recorded geographic coordinates with GPS receivers. These coordinates were used by the pilot for navigational purposes, and aerial video was recorded over each field location to compare the ground and aerial perspectives of forest damage.

The hurricane study area encompassed 1.7 million hectares and contained 729,000 hectares of timberland according to the 1991 statewide inventory (Vissage *et al.* 1992). Most of the forest lands in the study area were located in the Atchafalaya River Basin, which was comprised predominantly of hardwoods of the oak-gum-cypress forest type. Primary tree species included baldcypress (*Taxodium distichum* (L.) Rich.), water tupelo (*Nyssa aquatica* L.), and willows (*Salix* L.). Other bottomland hardwood species included, but were not limited to, cottonwoods (*Populus L.*), sweetgum (*Liquidambar styraciflua* L.), oaks (*Quercus* L.), elms (*Ulmus* L.), ashes (*Fraxinus* L.), sugarberry (*Celtis laevigata* Willd.), and red maple (*Acer rubrum* L.).

Video image samples were captured from video tape at 0.8-kilometer intervals along each flight line. The flight lines were spaced at 16-kilometer intervals. This pattern produced a sampling intensity twice that of the 4.8-kilometer grid spacing of the Midsouth-FIA field plots. The 55-millimeter focal-length lens and a flying altitude of 600 meters provided a video swath of 96 meters in width and a video image footprint of 96 by 72 meters (0.69 hectare) for each sample location. Each video image covered an area slightly larger than the ground area covered by a forest inventory field plot (0.4 hectare). Image resolution for this altitude and focal length was 15 centimeters per picture element.

The digital image files were interpreted visually for forest-type-group composition and rated for broad categories of damage severity to the merchantable boles and canopy structure. The three forest-type categories were baldcypress, hardwoods, and pine. Damage severity consisted of a no-damage category, three broad percentage categories for basal area bole damage (breakage or blow-down), and two categories for canopy damage.

The percentage values for bole damage were applied to the geographic locations in a GIS, and a plot of this point file was generated. A focal-mean value was computed for each data point along the flight lines. These focal-mean values were used to draft contours across the map surface to delineate zones of similar forest damage. The resultant polygons represented five zones of forest damage within the study area: (4) severe, (3) moderate, (2) light, (1) scattered light, and (0) little or none (Figure 1).

These techniques were developed during the assessment of forest damage from the hurricane to extract volume data from the recently completed field inventory database. Percentage of damage for each polygon was applied to the data for field inventory plots for each field plot that fell within the respective polygons (Kelly 1993). A timber damage report was generated portraying alleged volume loss by forest type and total volume loss within each damage zone. Total land area for each damage zone was generated from the GIS. However, the area of timberland by forest type for each damage zone was retrieved from the field inventory database.

Ice storm, North Mississippi-1994

Similar techniques using airborne video sampling were developed to assess the timber damage caused by a major ice storm that passed through north Mississippi in February 1994. Major timber losses occurred during this severe storm, which formed in the Great Plains and moved across the central eastern United States (NOAA 1994). Precipitation in the form of freezing rain and ice began in Texas and moved eastward to Washington, D.C. and the Atlantic seaboard. After the

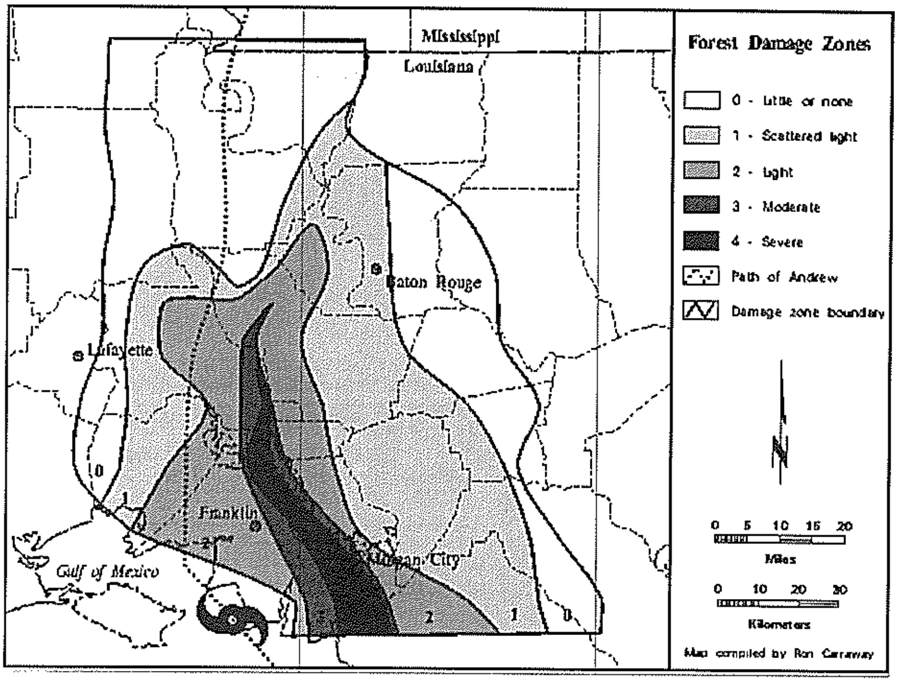

Figure 1. Path of Hurricane Andrew in southern Louisiana and zones of forest damage.

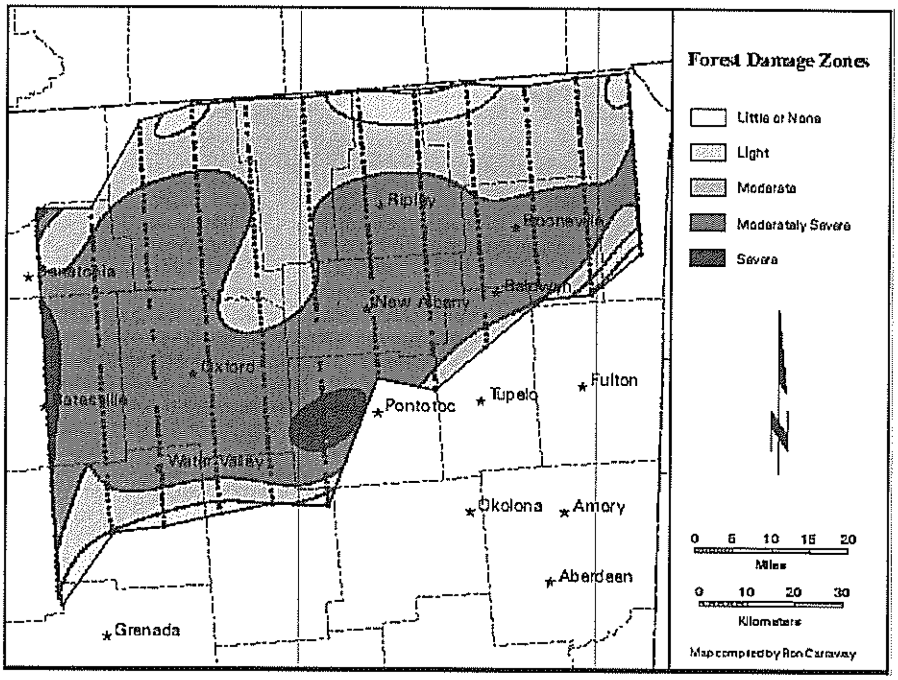

Figure 2. Study area following the ice storm of 1994 in northeast Mississippi showing forest damage zones and the locations of the aerial video/GPS samples.

storm had passed through north Mississippi, the timber damage was estimated at $1.3 billion. In contrast, the timber harvest, the most valuable agricultural commodity in Mississippi, was estimated for the entire state to be $1.02 billion in 1993 and $1.07 billion in 1994 (MCES 1995).

Midsouth-FIA had completed the field inventory for north Mississippi counties during 1993 (Faulkner *et al.* 1993). Similar to the impact of Hurricane Andrew, the integrity of the field inventory database had been affected by the ice storm. Likewise, the Mississippi Forestry Commission wanted to perform an assessment of timber damage for fire hazard mitigation. A cooperative effort was undertaken to acquire north-south aerial video transects somewhat perpendicular to the path and iso-line severity of the ice storm.

Although the forest damage was severe and widespread from the Mississippi River to the Alabama state line, the study area was limited to the more heavily forested region in the northeast corner of the state. The northwest corner of Mississippi was comprised of mostly agricultural lands and contained only limited areas of forest lands. It would have been difficult to perform aerial video transect procedures on such scattered tracts of forest land. This problem limited the study area to 1.3 million hectares in the eastern half of the portion of Mississippi that was besieged by the ice storm. And, according to the 1994 inventory data, the study area contained 764,000 hectares of forest land. Thus, the areal extent of the study was less than that of the hurricane study, but this study area contained more forest land.

The dominant forest type of oak-hickory comprises about half of the timberland for this area of the state. Loblolly-shortleaf pine, oak-pine, and oak-gum-cypress forest types make up the majority of the other half. Principal tree species for northeastern Mississippi include oaks (*Quercus* L.), hickories (*Carya* Nutt.), shortleaf pine (*Pinus echinata* Mill.), loblolly pine (*Pinus taeda* L.), redcedars (*Juniperus* L.), gums (*Nyssa* L.), sweetgum (*Liquidambar styraciflua* L.), baldcypress (*Taxodium distichum* (L.) Rich.), elms (*Ulmus* L.), red maple (*Acer rubrum* L.), yellow-poplar (*Liriodendron tulipifera* L.), ashes (*Fraxinus* L.), and sugarberry (*Celtis laevigata* Willd.).

The vertical aerial video imagery was sub-sampled along each flight line at 1.6-kilometer intervals, and flight lines were spaced at 14.5-kilometer intervals. The sampling intensity and spacing in this study were slightly different from those of the hurricane study and provided a sampling intensity roughly equal to the number of Midsouth-FIA field plots in the study area. A flying altitude of 660 meters and maximum zoom of 66 millimeters for the focal length of the camera lens provided a video image footprint of 88 by 66 meters (0.58 hectare) for each sample location. This area coverage was slightly larger than the ground area covered by a forest inventory field plot (0.4 hectare). Also, a slightly higher flying altitude and a different camera lens were used for this study, which still produced a similar image resolution of 13.75 centimeters per picture element.

GPS coordinates, encoded onto the video imagery in-flight, were used to name each of the 579 digital image files as they were captured from video tape. Example, 34d21.0823n89d19.1079w was the file name of the video frame sampled at 34 degrees, 21.0823 minutes north latitude and 89 degrees, 19.1079 minutes west longitude. Although GPS coordinate precision as written may insinuate 15- to 18-centimeter accuracy, the single fix position of each video frame is only accurate to the GPS standard of 100 meters 95% of the time. This accuracy value is further eroded by tip and tilt of the airplane.

The file names were easily input, as geographic coordinates, to a GIS to create a point cover of the video sample point locations and associated damage-condition attributes. Each digital video image was interpreted for percentage of pine versus percentage of hardwood. Damage conditions were classified separately for each species group because pines were more susceptible to ice damage than hardwoods. In a watershed study in north Mississippi, Halverson and Guldin (in press) determined that pines received more stem breakage than hardwoods from the ice storm. Three small watersheds that had received 100% inventories in 1993 were devastated during the ice storm of 1994. Complete inventories were again performed after the ice storm. Comparative results showed that pines received 72% stem breakage, whereas hardwoods received only 15%. Overall, damage assessments indicated that 88% of pines were affected but only 37% of hardwoods received some type of ice damage.

Techniques originally developed during the assessment of forest damage from the hurricane were used in the assessment of forest damage from the ice storm to extract volume data from the recently completed field inventory database for north Mississippi counties. The geographic locations of the video samples and corresponding damage values were used to contour a GIS polygon cover designating areas of similar forest damage. Quartile estimates for percentage of damage were represented by the following values: 0 = no damage, 1=1-25%, 2=26-50%, 3=51-75%, and 4=76-100%. The Midsouth-FIA plot locations were compared with the damage zone polygon cover for a general analysis of the inventory database. The estimated percentage of downed timber for each damage zone was applied to the inventory database, and reports were generated to portray the alleged volume loss by forest type within each damage zone and the area of timberland by forest type for each damage zone. Total land area for each damage zone was generated from the GIS. Estimates of bole and canopy damage were combined to portray areas of potential fire suppression hazard for the planning efforts of the Mississippi Forestry Commission (Figure 2).

International cooperations

Mapping the forest distributions of Mexico and Central America

In January 1993, through the cooperation of the Mexican Secretaría de Agricultura y Recursos Hidráulicos (SARH), aerial video transects were flown across five separate TM-scene locations in Mexico to demonstrate the versatility of georeferenced airborne videography (Eggen-McIntosh *et al.* 1993). The aerial video data acquired during this mission were used to verify vegetative cover interpretations of Landsat TM prints for the global tropical Forest Resource Assessment 1990 Project developed by FAO (Eggen-McIntosh *et al.* 1994). The same aerial video is being used as part of a current project to map the forest cover of Mexico and Central America using AVHRR 1-kilometer resolution data (Lannom *et al.* 1994).

In the current project to map the forest distributions of Central America and Mexico, the video imagery is being used to verify digital classifications of 30-meter-resolution TM data. The verified TM data are then used to model the percentage of forest cover within the 1-kilometer AVHRR cells. The GPS coordinates provide geographic reference locations for orienting the aerial video imagery to the georeferenced TM imagery. Classifications of 20-meter resolution data of the Système Probatoire d'Observation de la Terre (SPOT) are also being used in the AVHRR modeling process, but no aerial video has been acquired over the SPOT data.

Approximately 4 hours (4-5 flight lines, 700 kilometers) of video transects were flown across each TM scene location at a nominal altitude of 1,000 meters above ground. This effort proved rather difficult over the mountainous terrain, and the altitude above ground actually ranged from 200 to 2,000 meters. The TM scene location in the Yucatan Peninsula was flown at 500 meters to remain below the low cloud ceiling. A camera lens with an 8.5-millimeter focal length was attached to the camera head to produce a video ground swath calculated to be 1,035 meters using the camera distance of 1,000 meters above ground. Thus, ground swath approximated flying height above ground.

Figure 3 shows airborne video flight lines across TM scene locations in Mexico. Flight lines were selected to cover forest areas highly susceptible to shifting agriculture patterns. (Shifting agriculture refers to land-use areas that have been shifted from forest to agriculture over a short period of time and have reverted to forest regeneration cover after being abandoned.) Designated turning points along the flight lines were selected from prominent natural or cultural features on flight maps for ease of location from the air, points that would possibly be visible from the previous turning point. Geographic coordinates for the turning points were charted from the flight maps and input to the GPS receiver for navigational purposes. As with the Hurricane Andrew study, hand held GPS receivers were used by field crews to gather ground coordinates of interest. These geographic coordinates were entered into the aircraft GPS receiver for navigational purposes, and video was flown over each field location.

Monitoring the natural resources of Senegal

Airborne videography was one of the remote sensing tools chosen to be incorporated into the "Long Term Monitoring of the Natural Resources of Senegal Project" being conducted in west Africa by USAID and EDC (Tappan *et al.* 1994). Environmental and socioeconomic data are being collected to monitor the effects of a lengthy drought in sub-Saharan Africa and to develop a better understanding of the long-term impacts on the natural and agricultural resources of Senegal. Extensive ground work and satellite image mapping began in 1982. Aerial video data will represent one of four levels of the environmental and socioeconomic data for the Senegal project (Wood *et al.*, in press). The four major levels of data are (1) biophysical assessment at historical ground sites, (2) socioeconomic data at the same ground sites, (3) repetitive airborne videography missions, and (4) satellite remote sensing.

EDC invited the Southern Research Station to participate in a joint effort with Senegal's Centre de Suivi Ecologique to develop the initial airborne video sampling techniques throughout the country of Senegal. Airborne video was selected for a variety of reasons. To monitor the agricultural and natural resources, aerial imagery should be acquired near the end of the rainy season when crops and vegetative cover are at peak greenness and before harvest. Aerial photography missions are flown infrequently, and cloud cover during the rainy season limits availability of cloud-free aerial photos and satellite imagery. Aerial video can be acquired under cloud cover, and parts of the mission may be rescheduled if inclement weather persists. Also, zoom capabilities and selection of flying height in airborne video permit a higher spatial resolution of the acquired imagery than do satellite imagery and most aerial photography. The encapsulated GPS coordinates on the video imagery allow immediate georeferencing of the video data. The GPS-referenced video imagery also serves as a source of ground truth where physical data collection on the ground may be difficult or impossible to obtain.

The systematic transect sampling method was selected as the technique to develop using airborne videography. It is commonly used in environmental monitoring and statistical analysis of land use and land cover. A 20-kilometer point grid was generated across the country, and the points were connected to create north-south parallel transects spaced 20 kilometers apart. Flight lines were oriented north-south to capture the natural environmental gradient from the drier climate of northern Senegal (Sahelian zone) through the Sudanian zone to the moist tropical Guinean zone of southern Senegal and The Gambia. Future plans

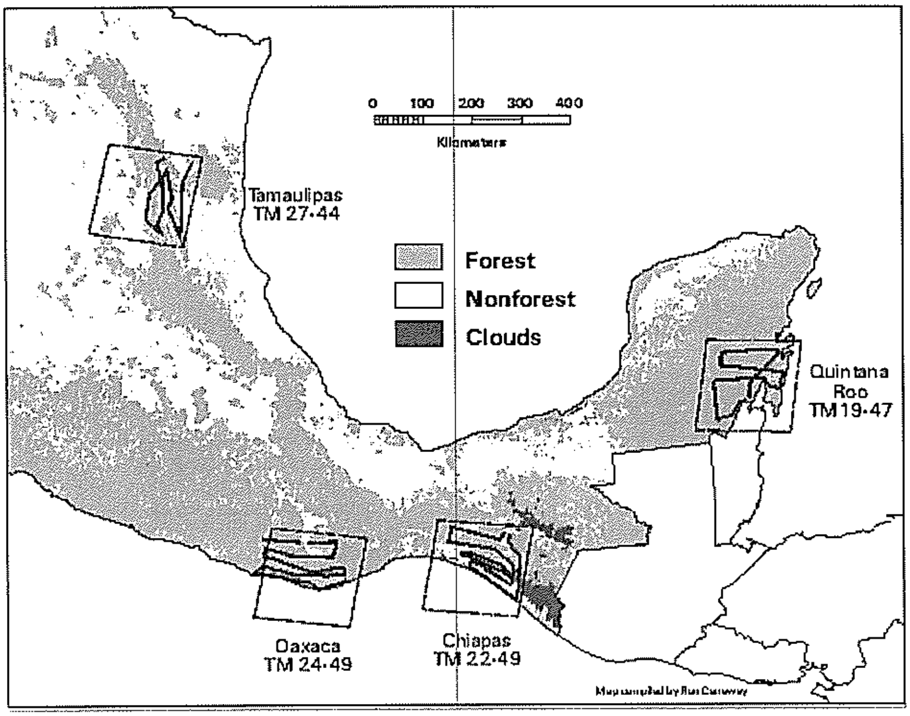

Figure 3. Location of video transects within Landsat TM scenes in Mexico.

Figure 4. GPS coordinates acquired near the end of the rainy season depicting airborne video transects and random flights over historical GPS ground sites throughout Senegal and the Gambia.

are to intensify the 20-kilometer grid with additional flight line transects spaced at 5- or 10-kilometer intervals. The video from this mission will be sampled at 20-kilometer intervals to maintain the square-grid sampling approach. However, the continuous video recorded along the transect does allow for sub-sampling between the 20-kilometer data point locations.

A Sony CCD-TR-700 Hi8 camcorder was provided by EDC as a second camera to record high oblique video in conjunction with the vertical video. The camcorder contained built-in image stabilization, and the Hi8 recording format produced higher quality imagery than the 8-millimeter-format videocassette recorder provided by the USDA Forest Service. The 11- to 66-millimeter telephoto lens on the vertical camera was set at the wide-angle view of 11-millimeters focal length. A flying altitude of 300 meters above mean sea level provided a nominal video swath of 240 meters. The zoom feature of the telephoto lens, when needed, provided a video swath of 40 meters. This flying height was maintained for consistency throughout the project, and because most of Senegal is only a few meters above sea level, increase in terrain elevation did not pose a problem. The oblique image of the second video camera provided a similar swath width (300 meters) at the bottom of the image, ranging to 15 kilometers in width at the horizon near the top of the image. Both cameras were connected to the color monitor, and alternate camera views could be selected using the monitor.

Over 70 hours of aerial video were recorded simultaneously with each camera, covering approximately 13,000 kilometers of flight lines (Figure 4). The project was completed after 16 days of flight time using a Cessna 206 airplane. Gray Tappan of EDC performed an excellent job in planning and logistics for the mission. Because aviation fuel was provided only in the capital city of Dakar, it was necessary to purchase new 200-liter drums of fuel and hire a ground crew to transport the drums to each of six regional airports for daily refueling. Also, it was essential that the fuel be transported to the correct airport and in a timely manner to prevent any delays in the work schedule as the video mission progressed across the country. Another problem involved installation of the oblique video camera underneath the airplane. A special metal box was fabricated to enclose and protect the camcorder from the elements (rain, sand, wind vibration, etc.). The camera box was mounted to the fuselage, and an airfoil was mounted in front of the metal box to reduce wind vibration. The camera was placed inside the metal box and, facing the rear of the airplane, was tilted downward until the horizon was only slightly visible to maintain the high oblique perspective.

Two 8.5-centimeter inspection ports were opened to facilitate mounting each camera. The vertical camera was mounted to the cabin floor with a quick-release device for easy removal, whereas the oblique camera remained mounted underneath the airplane for most of the mission. The inspection ports were large enough to provide easy access to the oblique camcorder for changing videotapes and making camera adjustments. The camcorder battery was connected to the power supply of the vertical airborne video system to maintain the battery chargeand provide constant power to the camcorder throughout the mission. This connection eliminated the need to replace batteries every 90 minutes and recharge batteries each night.

Summary

The airborne video system developed and utilized by the Southern Research Station has proven to be a valuable tool in situations that require rapid responses to natural catastrophic events that impact forests. Both wind (Hurricane Andrew) and ice damage were characterized spatially through interpretation of aerial video. GPS coordinates, encoded onto the video, facilitated the development of a GIS for each impacted area. These GIS coverages, coupled with existing data bases of forest resources, enabled analysts to develop estimates of timber damage soon after the storm events.

Aerial video is also being increasingly used in monitoring programs of other countries. Projects in Mexico and Senegal have demonstrated cost effective uses of video for verifications of satellite data interpretation and for basic resource monitoring. These projects have paved the way for planning additional cooperation in the use of aerial video technologies for developing programs for monitoring forest health in Indonesia and Honduras.

Past successful projects, current research, and future planned international cooperation provide an environment for continual improvement of video technology utilization for assessing forest resources. Plans for improving the airborne video system of the Southern Research Station include incorporating higher resolution recording, upgrading the GPS receiver to provide a choice of increased coordinate precision, a second camera and recorder for oblique viewing, automated sequential data capture and mosaicing, and a digital capture board and computer for in-flight digital image capturing.

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APPLICATION OF MODERN INVENTORY TECHNIQUES IN THE JARRAH FORESTS OF WESTERN AUSTRALIA

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Abstract

Modern technology enabled the Department of Conservation & Land Management to complete a rapid resource-level inventory of 1.4 million hectares of jarrah (*Eucalyptus marginata*) forest in Western Australia.

Large-scale (1:1000) aerial photographs were used as the first phase of a two-phase sampling design. The photographs were obtained using twin cameras mounted on a helicopter, allowing the photographic scale to be determined automatically. Tree volumes were estimated from photographic measurements of tree height. Ten percent of all photo samples were double sampled on the ground.

GPS navigation was used to direct the helicopter along the desired flight-lines and to record the location of every photographic sample. This allowed the ground samples to be relocated efficiently and served as a record of sample locations in a Geographic Information System. GIS analysis also allowed volume estimates to be derived for any sub-unit of the forest, including numerous strata derived from complex GIS overlays.

Estimates of product assortments were derived using computer processing of recorded wood qualities. This allowed re-processing of volume estimates to cater for new log grades and changes in log specifications.

Processed data from the inventory and associated growth data for various strata were stored in a relational database and database analysis was used to simulate scheduling of harvesting operations for strategic planning. The database tools allowed rapid evaluation of different supply schedules and graphical presentation of the results.

Key words: Forest inventory, eucalyptus, aerial photography, GPS, GIS

Introduction

Some two million hectares of jarrah (*Eucalyptus marginata*) forest are managed by the Department of Conservation and Land Management (CALM) in the south west corner of Australia. Timber production is permitted in 1.2 million hectares that lie within the multiple-use zones of the forest.

Changes to log grades over time and a 1987 plan for restructuring the timber industry heralded the need for a new inventory of the forest. This inventory was to be completed within a three-year period, whilst providing relatively precise estimates of timber volumes by the standards often accepted for strategic inventory. Specifically, the inventory was to be able to provide localised estimates of sawlog volume within 25% (at 95% confidence) for any area greater than 10 000 ha. These areas were not to be pre-defined but dependent on future requirements. The design was also to accommodate the facility to partition the gross bole volume (GBV) into different timber grades and, without remeasurement, to repartition that GBV as utilisation standards changed.

The jarrah inventory was designed to make the fullest use of available technology to meet these objectives. This paper describes the application of the technology, the problems and benefits encountered in its use.

Application of technology in the inventory

The design objectives required that a relatively large sample be collected in a limited time, that the assessment of timber grades be flexible and that inventory results could be derived for any sub-section of the forest.
To meet these objectives, the data acquisition phase of the inventory made use of:
- large-scale aerial photography,
- GPS navigation, and
- advanced computer processing,

while the data analysis phase employed
- GIS analysis and
- relational databases.

Each of these are discussed in detail.

Large-scale aerial photography

Stratified random sampling is commonly applied in extensive inventory to maximise the efficiency of the sampling effort. In this case, however, the inventory was not to be constrained by pre-determined sampling units or strata.

Systematic double sampling was selected as an alternative - giving improved sampling efficiency while retaining the flexibility for post-stratification or re-sampling at later stages.

The first phase of the double sample was obtained using fixed-base, large-scale aerial photography (LSP) using a helicopter (Biggs and Spencer 1990). While photographs cannot be described as new technology in forestry, the use of large-scale photographs for forest inventory has been limited. The techniques were first developed in the 1970s in Canada, USA and Australia but there are only a few cases of their use in extensive inventories.

We found that precise estimates of tree height could be obtained for jarrah and marri trees for colour photographs at 1:1000 scale. Using a single-variable height-volume equation, these gave provided estimates of gross bole volume in one seventh of the time and one tenth of the cost of ground measurements.

Tree heights were best measured using simple parallax-type devices such as Interpretoscop and Stereotope instruments. Attempts were made to use small-format analytical stereo-digitisers but it was not possible to make full use of the fixed-base photographic system to constrain the stereo orientation in the digitiser. It therefore took too long to set up each photo pair for measurement - an inappropriate or mis-matched use of technology which was abandoned for this task.

GPS Navigation

Newer technology was added to the photographic system in the form of GPS navigation in the helicopter (Biggs et al 1989). This not only allowed the navigator to ensure that flight-lines were accurately placed across the forest, but enabled the position of each and every photo-pair to be recorded.

The GPS coordinates could then be input directly to the Department's GIS for later analysis, and to produce maps showing the sample locations. These maps were used by field crews to relocate the ten-precent sub sample for ground measurement. With the assistance of the photographs themselves, crews located the plots in an average of 30 minutes.

Besides conferring advantages in GIS analysis described later, the enthusiasm of field staff was increased by the novel use of photographs and GPS coordinates, which increased morale and productivity.

Field measurements and advanced computer processing

Once in the field plot, crews recorded the usual DBHOB and bark thickness. Spiegel Relaskops were then used to estimate upper stem diameters and bole length, giving more precise estimates of bole volume. (Laser devices were not available at that time, but would be considered now.) Instead of assessing the suitability of sections of the bole for log products, assessors recorded in detail the location, extent and severity of qualities associated with the bole (e.g. branches, rot, sweep, charcoal ... (Strelein and Boardman 1992). Husky Hunter data recorders were used to assist in data collection and on-site validation.

Computer processes were then applied to calculate volumes of different log grades under specified sets of rules. This could be done with confidence given the detailed measurements of upper-stem dimensions and the details recorded for each tree, an appropriate matching of technology. Re-allocation of the gross bole volume to log grades could be accomplished at any time with new sets of allocation rules, saving the need for re-measurement as specifications change or new log grades are proposed. Such processing on a large data set is only feasible now with modern processing power. Once this analysis was completed, the results were stored for each plot and tree in a relational database, allowing analysis and integration with GIS in the next stage.

GIS Analysis and Relational database

One of the design requirements was to be able to calculate volume estimates for any area of forest over 10 000 ha, no matter how they were defined. The GPS coordinates of each sample plot allowed this to be accomplished through the powers of GIS analysis.

The GIS (Arc/Info in this case) was used to define "windows" for which volume estimates were required. These may have been based on forest types or strata, distance zones from individual timber mills, administrative boundaries or any other map data held in the system. Once defined, the window polygons could be intersected with the point locations of the samples, and data from all of those samples within the window extracted from the relational database.

Similarly, results from the processed data could be displayed through the GIS to give visual representation of the timber volumes over different areas of the forest. This presentation allowed managers to visualise the results of the inventory much better than tables of numbers and added to the credibility and acceptance of the results.

Processed data were further refined in the relational database to model the flow of timber over time - "yield scheduling". Full use was made of Oracle's

SQL*Forms and SQL*Menus to facilitate user-friendly but controlled access to the data. These tools allowed rapid recalculation of yield schedules over 200-year horizons, a task impossible without this technology.

Conclusions

The inventory demonstrated successful application of many technologies. Results were limited only where the technology was not appropriate or not matched with other components of the system.

Aerial photographs and GPS navigation provided sampling efficiency, increased morale and production in field crews and the potential for linkage into GIS. The GIS and related computer processing allowed quick analysis and re-analysis of the data for varying log grades and varying land-bases. They also allowed improved presentation of results. The integration of all these tools provided credibility and the satisfaction of using the best available techniques to get the best and most cost-efficient results.

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THE FOREST RELEVANT INFORMATION IN MULTIFREQUENT RADAR DATA

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Abstract

Within the last years the application of radar image data has gained increasing interest, due to the fact that radar nearly provides independence from weather conditions. A study was carried out to present the information content of airborne multifrequent radar images for forest mapping in comparison to Landsat TM and Spot XS. The results for the radar image data as well as for the aforementioned optical data in general were rather bad, but the accuracy assessment showed for the radar image data in average approximately the same accuracy as for the optical data.

Key words: Remote sensing, multifrequent radar images

1. *Introduction*

Within the last few years the question of the use of radar image data for mapping and valuation of landuse classes has been discussed intensively, due to the fact that the improvements in data processing techniques and data quality allow a more easy application and interpretation of the data for all kinds of thematic mappings.

The attraction of using radar data is based on their weather independence and the expectation that radar might give information on the vegetation which is not visible or detectable by optical systems. The provision of air-borne and satellite radar image data and the aforementioned arguments called intensified research activities on the application of radar images in the field of forestry and landuse planning.

At the department of Remote Sensing and Landinformation Systems there are two projects investigating the information content of radar image data for applications in forestry. The following will present the results of the investigation on the **use of multipolarimetric and multifrequent airborne radar image data for forest mapping.**

2. Review on radar characteristics

RADAR, the synonym for Radio Detection and Ranging, is an active remote sensing system. An antenna located at the flight object transmits microwave pulses towards earth surface in a slant downwards and receives a backscattered signal from the earth's surface. Due to the fact that microwave pulses are transmitted in a slant downwards the area registered by the antenna is transposed aside of the flightline. This calls strong geometric distortions in the radar image but also allows the reflection of the relief in the image.

Radar sensors send energy in different frequencies of the microwave region from 3 mm up to more than one meter wavelength. The microwave pulses sent by the radar antenna are coherent waves. The coherent waves are swinging in a certain plane towards the object and from the object towards the sensor. The inclination of the wave swinging plane in respect to the earth surface and the way the wave is propagating is expressed by the polarisation status. The wavelength and the polarisation status are important parameters, because depending on these microwave characteristics the backscatter signal varies for different objects and helps to discriminate them.

3. Description of the objectives and materials

A project investigating the potential of airborne radar image data for forest mapping was started in 1991. Objectives of the investigation were:

- Test different analysation tools for the evaluation of polarimetric radar image data
- Analyse the polarimetric information content in C-, L- and P-Band for forest stand type discrimination
- Compare the discrimination power of the polarimetric multifrequent radar image data with optical data sets

The test area for the investigations was located in the south of Germany near Munich at a Latitude of 48° 04′ and a Longitude of 11° 11′.
The forests of the test area are characterised by homogenous stands with the main tree species:

spruce (*picea abies*)
pine (*pinus sylvestris*)
beech (*fagus sylvatica*)
mixed stands (*larix decidua, alnus glutinosa, betula pubescence, pinus strobus*)

and the age classes:

thicket
pole wood
timber.

The flight parameters were characterised as follows:

pixel projection	slant range
pixel resolution	6.6 m slant range
	12.5 m azimuth
pixel size	12.5 m x 12.5 m
polarisation	quad-pol mode
frequencies	C-band (5.6 cm)
	L-band (24 cm)
	P-band (68 cm)
local incidence angle	45° (DLR runway)
flight direction	180°
flight altitude	4918 m
flight date	12th of July 1991
flight time	1.15 p.m. GMT
image size	1099 x 1024 az x rg

and for the verification the following ancillary data were available:

digital forest map
forest inventory map (88/89)
aerial infrared photographs (1 : 23 000)
field data (height, crown closure, understory vegetation, crown length)

4. Methods and results

The analysation of data was divided into the following steps

- **preprocessing**
  calibration
  rectification
  transformation into 16 bit digital data
  incidence angel correction
- **signature analysis**
  visual polarimetric signature analysis
  discriminant analysis

- **filtering**
  Lee speckle filtering
- **classification**
  Maximum Likelihood classification
  EBIS evidence based classification
- **post classification filtering**
  median filtering
- **verification**

4.1 Visual analysation of the influence of polarimetric status on the backscatter signal

After preprocessing of the data the influence of the polarimetric status on the backscatter signal was analysed for each wavelength. In order to do this for each stand type present in this forest area, training plots were delineated and the backscatter signal was calculated in 5 degree polarisation angle steps. The interdependence between polarisation and backscatter signal was visualised by polarisation diagrams.

Based on the visual analysation of the polarisation diagrams 153 polarisation states were defined for further investigation.

4.2 Statistical signature analysis

Next, the predefined polarisation states were statistical analysed. Using the analysation package SAS the discriminant power Wilk's lambda between the defined stand types was calculated for different channel combinations. The analysation provided an ordered selection of the best channel combinations and their discriminant power.

Based on the results of the statistical analysations a final definition of the forest classes, which can possibly be discriminated, was carried out. The following classes were defined:

LANDUSE CLASSES
- forest
- housing areas
- agricultural land
- water
- golf course

FOREST CLASSES
- deciduous timber (beech)
- spruce timber

- spruce pole wood
- pine thicket
- mixed pine-deciduous pole wood
- mixed conifer-deciduous pole/timber

After filtering of the speckle based on the finally defined classes a divergence analysis was carried out for the radar data in comparison to Landsat TM data and SPOT XS data. For the divergence analysis the Jeffries Matusita distance was calculated on the basis of the training plots. The calculations were provided separately for the landuse classes and the forest classes. The results of the divergence analysis proved that in general the discriminant power of the radar data set is slightly superior to the Landsat TM and the SPOT XS data (Table 1). To valuate this it has to be taken into account that the spatial resolution of the optical data was smaller than the radar data what might be a result of a higher amount of mixed pixels in a worse spectral discrimination. In addition, the discrimination power varies between the 3 data types depending on the forest classes, which means that for one forest class radar can have the highest discrimination power while for another forest class optical data have the highest discrimination power.

Table 1. ***Jeffries Matusita Distance calculated for the defined landuse classes and forest classes based on radar, Landsat TM and SPOT XS data.***

Landuse classes

landuse class	*sensor type radar*	*sensor type Landsat TM*	*sensor type SPOT XS*
golf-agri	1201	1154	904
golf-forest	1414	1414	1374
golf-water	1414	1414	1414
agri-forst	1409	1195	1286
agri water	1406	1413	1414
forest-water	1414	1414	1405
Ave	1386	1334	1299
Min	1201	1194	904

Forest classes

forest class	*sensor type radar*	*sensor type Landsat TM*	*sensor type SPOT XS*
spruce 4/spruce 3	1174	1174	1072
spruce 4/deciduous 4	1347	1410	1414
spruce 4/mixed stands 3	753	868	1123
spruce 4/pine2	1411	1249	1413
spruce 3/deciduous 4	1408	1413	1411
spruce 3/mixed stands 3	1265	1172	676
spruce 3/pine2	1414	1071	1345
deciduous 4/mixed stands 3	1049	1175	1284
deciduous 4/pine 2	1320	1395	1412
mixed stands 3/pine 2	1335	921	1094
Ave	1228	1102	1110
Min	735	868	676

* best separability is 1414

The signature analysis proved that the best channels for forest class separation is in general the P-band in HH polarisation and L-band in HV polarisation.

4.3 Classification

After the signature analysis, a classification based on the Maximum Likelihood classifier as well as on the evidence based EBIS classifier was carried out. The classification was based on the 14 best channels defined by the statistical discrimination analysis. At first the separation of forest and non-forest land was investigated. Besides some housing areas, which are characterised by big gardens with old trees, the results proved for radar data a high accuracy for the delineation of forest land against non-forest land.

The classification of the housing areas was not based on the separable spectral classifier but on the window classifier EBIS which takes into account textural information. This was easy to carry out, just like a visual classification in which the textural information can be implicated by the interpreter.

Compared to optical data the separation of forest and non-forest land was more precise on the basis of radar data.

Next, a landuse classification was provided after masking the housing areas. As it was to expect from the previous statistical analysation, a more precise landuse classification of the radar image than that for the optical image was obtained.

After classification of the landuse classes and masking of the forests within the forest areas a classification of the defined forest classes was carried out. The classification results look tentatively good if they are visually compared to the forest inventory map. Nevertheless the error matrix (Table 2) and index of agreement (Table 3) prove that in summary for all data types no good classification results were obtained. In general the optical data seem not superior to the high resolution airborne radar data. It has also to be pointed out that according to the obtained accuracy a different order of forest classes is provided for each data type, what points towards a complementary effect of the different data sets.

Table 2. Error matrix analysis for the forest classes based on the spectral classification results of the different data types.

Radar Data

	conif	*fijg*	*laub*	*conmi*	*kijg*	*total*
noclass	0	0	15	6	0	21
conif	549	154	5	50	0	758
fijg	248	3273	5	70	0	3596
laub	114	3	1226	214	0	1557
conmi	1393	924	1104	2915	375	6711
kijg	0	0	0	22	117	139
total	2304	4354	2355	3277	492	12782

Radar / Optical Data

	conif	*fijg*	*laub*	*conmi*	*kijg*	*total*
noclass	3	6	5	20	0	34
conif	795	176	16	126	3	1116
fijg	140	3429	16	43	3	3631
laub	151	15	1608	331	0	2105
conmi	1215	728	710	2624	345	5622
kijg	0	0	0	133	141	274
total	2304	4354	2355	3277	492	12782

Landsat / TM

	conif	*fijg*	*laub*	*conmi*	*kijg*	*total*
noclass	101	121	28	204	44	499
conif	897	349	10	201	29	1486
fijg	206	2890	23	91	40	3250
laub	170	33	1567	313	1	2084
conmi	928	932	726	2394	261	5241
kijg	2	29	1	73	117	222
total	2304	4354	2355	3277	492	12782

SPOT XS

	conif	*fijg*	*laub*	*conmi*	*kijg*	*total*
noclass	0	19	4	143	2	172
conif	904	161	6	99	3	1173
fijg	722	3425	189	292	156	4784
laub	195	54	1764	452	5	2470
conmi	471	637	383	2065	172	3728
kijg	8	58	9	226	154	455
total	2304	4354	2355	3277	492	12782

Table 3. Index of agreement (Kappa) for the forest classes based on different data sets.

Radar

Classes	*Reference Pixel*	*Reference GIS Map*
conif	0.6636	0.1903
fijg	0.8638	0.6545
laub	0.7394	0.4541
conmi	0.2393	0.7674
kijg	0.8354	0.2294

Radar / Optical Data

Classes	*Reference Pixel*	*Reference GIS Map*
conif	0.6491	0.2824
fijg	0.9156	0.7033
laub	0.7106	0.6203
conmi	0.2829	0.6443
kijg	0.4952	0.2710

Landsat-TM

Classes	*Reference Pixel*	*Reference GIS Map*
conif	0.5165	0.3090
fijg	0.8320	0.5491
laub	0.6959	0.6002
conmi	0.2695	0.5433
kijg	0.5081	0.2243

SPOT XS

Classes	*Reference Pixel*	*Reference GIS Map*
conif	0.7202	0.3310
fijg	0.5692	0.6590
laub	0.6496	0.6889
conmi	0.4001	0.4779
kijg	0.3120	0.2877

5. Conclusions

- Radar images based on longer wavelength seem quite useful for forest classification
- A very distinct separation between forest land and non-forest land seems possible
- The radar signal is mainly dependent on surface roughness and therefore forest parameters which are correlated with roughness will successfully be discriminated by radar.

- A combination of radar and optical data and a stepwise classification will improve the results compared to separate classifications of optical or radar data.
- Most probably radar will remain an additional option to the optical systems, because the data are more difficult to interpret than optical data
- The existing radar satellites in general do not provide the optimal bands for successful mapping in forestry and landuse.

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IMPLEMENTING NEW TECHNOLOGY IN DEVELOPING COUNTRIES: OPPORTUNITIES AND IMPEDIMENTS

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Abstract

Digital Space Remote Sensing, Geographic Information Systems and Digital Elevation Model (GIS/DEM), Hardware and Software Technologies, Global Positioning Systems (GPS), Data Capture Devices, Data Loggers, Laser Dendrometers, etc., offer exciting possibilities for assessing and monitoring global natural resources at reduced costs and increased speed and precision. In non-industrialized countries, the widespread use of these technologies is hindered by the lack of skilled personnel, inadequate technical and scientific structures, difficulty in transferring information to the final users and by insufficient international cooperation to boost local research and improve information flow. The incapacity or the political unwillingness to modify economic and social conditions, which causes an unsustainable use of the ecosystems, very often slows down the implementation of efficient techniques of monitoring and hinders utilization and distribution of collected data. The introduction of new technologies is expensive because it requires a re-organization of the services, hiring of specialized staff and substantial investment to satisfy the technical structures and solve logistic, administrative and operational problems that prevent implementation. Imported technology can contribute effectively to the sustainable management of resources if adapted to specific environmental, social and economic conditions of developing countries. Coordinated efforts at an international level must be taken to standardize classification systems, harmonize assessment and monitoring techniques, develop integrated inventorying systems and promote the exchange and transfer of information and technology on a non-commercial basis.

Key words: Monitoring technologies, developing countries, technology availability, research and development

Introduction

In the very near future forests and trees will play a fundamental role in sustainable development and environmental protection and the main issue for forthcoming years at global level will be containing forest destruction and land deterioration in the humid tropics, stopping desertification in arid regions, promoting a sustainable use of natural resources, improving the productive capacity of wastelands and cleared forest lands, guaranteeing food security for poor farmers increasingly threatened by the deteriorating of forests and natural ecosystems. The international public opinion has urged the forestry community to strengthen forestry institutions; enhance the scope and effectiveness of activities related to management, conservation, and sustainable management of forests, and effectively ensure the sustainable use and production of forest goods and services in both developed and developing countries (UNCED 1993). Several global conferences and scientific and technical meetings have repeatedly stressed the need of strengthening the national and international institutions' capacities to acquire knowledge about the forest's protection and biodiversity's conservation and to face human impact on the global environment. While the forestry tasks widen and the problems of achieving a sustainable management of natural resources are becoming increasingly complex and manifold, involving the whole biosphere and even the life's basis of future generations, "forestry is desperately starved of resources, the activities of forestry institutions are being made irrelevant by activities in other sectors, and there is an appalling lack of consistency and coherence in our approaches to some of the world's most important resource management problems" (IUCN 1992).

In 1990, Gregersen et al. (1990) estimated at 11,964 the number of forest researchers (6,716 research scientists and 5,248 technicians) working in tropical countries. This number has certainly increased over the last five years, but there is no doubt that the shortage of professionals active in the tropics still remains crucial and this, coupled with the lack of technical and financial means and the intrinsic difficulties of operating in a hard and scarcely known environment, represents a major obstacle for implementing a sustainable management of forest resources. In spite of some remarkable results, forest research in developing countries has not worked out effective solutions and sufficient knowledge to face the problems of sustainable forest development, may be due also to inadequate national and international political supports. The lack of trained personnel, insufficient incentives for improving research standards, limited financial resources, poor research organization and management, lack of critical mass of scientists, unsatisfactory access to information and research facilities are some of the most relevant factors preventing the improvement of the knowledge and the development of suitable strategies to overcome deforestation, desertification and environmental degradation. Sometimes international aids to developing countries have been conditioned by supplying technologies, but with an external assistance only for a short time, leading to believe that the imported technology could replace national research. But "a country without the scientific ability is a barren society. It will never be able to compete and will always be dependent upon others. Even if such countries are independent politically, economically, they will always be colonies of scientifically advanced countries" (Nor Salleh 1991). Local research in developing countries is not progressing and the technological gap between North and South is increasing with the downfall of forestry and agricultural services and with the increasing economic difficulties of the universities and research institutions all over the tropics.

As the environmental problems are urging and financial, and institutional capabilities are limited, the researchers should concentrate their efforts on improving the sustainable management of natural ecosystems, on setting up sustainable consumption and production objectives, and on monitoring sustainable development progress. Technology can actively promote a sustainable development by providing tools for improving the use of natural resources and reducing throughput and waste, and by broadening the range of potential substitutes among natural and human-made resources and by finding alternatives to scarce resources.

However, a new global development model is needed to develop new environmental technologies. Industrialized countries are called to undertake a less-resource-intensive lifestyle, to reduce population growth and to elaborate development strategies, which can produce a shift from quantitative and material growth to qualitative and non-material growth. International trade rules furthering unfair commodities exchanges between industrialized and developing countries must be modified, and Southern countries should have free access to information and innovation on a non-commercial base. The costs deriving from the consumption of scarce natural resources or from environmental pollution ought to be fully internalized in the production processes. As energy and the resource efficiency of the "industrial world economic model" is still highly insufficient and does not provide permanent growth, it has to be changed (Simonis 1990).

During the past decades cheap energy and raw material prices have compelled the poor countries to overuse their resources and thereby to deteriorate their environment, while, on the other hand, this large availability of cheap raw materials has not forced the industrial countries to introduce innovative processes to reduce energy and raw materials consumption or to recycle waste. Developing countries are very often supplied with inefficient, polluting, and out-of-date technologies, which can't be used in industrialized countries any more, due to environmental and health law restrictions. In most tropical countries, the low costs of tropical timber have not compelled logging and wood enterprises to reduce wastage and improve efficiency and quality. In natural resources monitoring an over-optimistic reporting of the "potential" application of space born digital remote sensing for monitoring natural resources and an aggressive marketing policy carried out by remote sensing and GIS organizations, largely supported by international developing aids, have urged many Southern countries to adopt technologies not yet fully operational. There is still a "dearth of reliable facts and figures which could help to separate effective operational and quasi-operational systems and techniques from research and development" (Howard and Reichert 1986), and we risk providing unneeded information or offering information that we cannot supply, or which is too costly and requires such institutional and organizational changes that cannot be supported by the users.

Technology transfer

"In its broadest and simplest form, technology transfer is defined as the process of conveying new information in a form that can be understood and evaluated, and which will result in an informed decision to reject or adopt the innovation. An innovation is something new or the modification or adaptation of something already known. Innovations can range from new computer software, to silvicultural practices, to approaches for resolving conflicts among organizations" (Hobbs et al. 1993).

The problem of the diffusion of useful innovations to practitioners has been studied by thousands of scientists of different disciplines from various perspectives (historical, ethnological, social, economical, etc.) and innumerable studies have been carried out to improve human activities by means of new technologies or new findings. Technology transfer should be regarded as a process subjected to a chain of related elements which affect in various and complex ways its flow to the final users. Numerous authors have adopted a system approach in analyzing technology transfer and diffusion, which allows to identify the critical elements affecting the process and their interrelationship. The major factors of the process are (Murth and Henddee 1980):

- the characteristics of innovation
- the media used to communicate information about innovation
- the individual and group processes required for adoption
- the characteristics of the social system in which the innovation is diffused.

In several industrialized countries special institutions look after extension and supply the users with technical assistance to apply innovations, but such institutions do not exist in most developing countries. In these countries the acquisition of new findings results more difficult because of the lack of many pre-requisites necessary to accomplish successfully the transferring process and spread out new technologies and new knowledge. Motivation, professional and managerial engagement for searching new information and changing traditional working methods are in most cases insufficient. Social structures responsible for applying new findings have limited technical and operational capabilities and are insufficiently motivated. The centralized and hierarchized administrations and services are unable to operate effectively, collaborating actively with the final users. Research institutions, on the other hand, sometimes are not up to adjusting to local conditions the techniques developed in a different social, economic, and institutional environment.

The introduction and diffusion of new utilization and transformation systems of forest products and new forestry practices for the amelioration and conservation of forest ecosystems progress more slowly in forestry than in agriculture, due to the higher risks linked to the long time horizon, to the predominance of state ownership, and to the many conflicts over resource management, which sometimes involve local and national-interest groups and even international opinion and affairs. Since forest officials are already unnerved by the burden of tasks they have to face to achieve a better use of forest resources, without receiving adequate rewards for their risks in applying new techniques, they don't care to apply innovations, which are often not understood by politicians and decision-makers (OTA 1994).

The adoption of innovations depends on the relative advantages (economic, labor and resource savings, etc.), which can be achieved and on the quality of the expected results. Developing countries are usually not in the position to effectively use complex equipment and technologies, which require special training or whose practical results are not immediately evident for the final users. Similarly sampling and measuring techniques, complicated data handling procedures or forest management systems requiring a high professional expertise and special training of executives are not easily adopted and effectively applied. Innovations are more easily adopted if they are simple to use and to learn, ready for multiple uses and if the results can be appreciated very soon. However potential final users have to be directly informed through suitable media, stimulating their disposition to evaluate and to try the innovations. It is required to identify final users as well as the decision maker level, where new technologies are approved and released. But the effective implementation of new findings also requires that the political decision makers possess the technical knowledge, the social authority and the credibility to persuade final users to apply them.

Natural resources monitoring technologies

Since the introduction of mathematical statistics techniques and aerial photographs at the beginning of the century, forest resources assessments and monitoring have made an enormously rapid progress. The widespread use of computers, digital remote sensing, GIS (Geographic Information Systems, GPS/DEM (Global

Positioning Systems/Digital Elevation Models, laser dendrometers, data loggers, radio tracking devices and other electronic instruments for automatic and remote recording of environmental information has made overall controls of the global natural resources possible. These new technologies offer the possibility to accomplish more with fewer means and enable to collect and handle a large amount of data to monitor fauna, vegetation and environmental characteristics and dynamics. Computer analyses conducted over a certain period are able to extrapolate recorded data across wide regions and improved computer programming languages allow to develop reliable models on environmental and resources changes. Geocoded permanent sample plots enable to detect vegetation changes and to control forest growth and timber drain, while new measuring devices allow assessing height, volume and biomass of trees and stands with increasing precision and speed. However the use of these technologies for monitoring forest ecosystems requires expertise, practical knowledge, interdisciplinary teamwork, financial and technical support, and a rationalization of working and institutional activities, which are often lacking in developing countries.

From a theoretical point of view natural resources inventorying and monitoring has become relatively easy with the many satellites, orbiting around the Earth, equipped with various active and passive sensors. But from a practical point of view there are manifold complications in gathering data in certain geographical areas and in setting up management programs in tropical forests, where different information have to be combined and integrated and where manifold interacting factors need examining to overcome "the vicious circle of population pressure, deforestation, and rural depression in the tropics" (Palo 1990).

Since the launch of the first satellite (ERTS) in 1972, the use of electromagnetic sensors to monitor the Earth's surface and atmosphere on a regional and global scale has enormously increased and the subsequent development of GIS (Geographic Information Systems) capable of collecting, storing, manipulating and displaying spatial data from different information sources, offer exciting possibilities of assessing and monitoring forest resources both in industrial and developing countries. In spite of the many positive results obtained in industrialized countries, these technologies have been poorly implemented in developing countries, due to manifold environmental, economic and social barriers.

The major environmental drawbacks when using space borne remote sensing technology are:

- Insufficient usable data due to cloud cover especially in the tropical rain forest areas and uncertainty of image availability at a specific date hampers the possibility of monitoring dynamic land use and forest changes. Radar images may overcome in future these difficulties, but further research is needed before active remote sensing becomes fully operational (Raney and Specter 1989)

- Low spectral and spatial resolution restrains the recognition of forest types and land uses changes, even for experienced interpreters using sophisticated image analysis systems
- Ground truth information for the setting up of image interpretation keys, for establishing training areas and for assessing information quality are generally lacking, thus preventing the application of comparable vegetation cover classification systems and the improvement of remote sensing information quality.

In the past Remote Sensing was regarded as a tool for assessing natural resources and for studying the environment. Ground survey was considered essential for validating interpretation, acquiring new supplementary information and assessing the "ground truth". Sampling techniques have provided powerful tools for reducing field work, assessing data quality and making inferences. Excellent sampling designs have been devised to combine remote sensing and field data, to provide reliable estimates of existing resources and environmental changes. However many natural resources inventorying and monitoring projects carried out in developing countries with international aids rely almost entirely on remote sensing and centralized analysis of digital data. Few ground controls carried out with loose sampling designs and weak surveying procedures are used to validate natural resources. Sometimes the environmental classification systems are developed in laboratory and the information needs are not properly assessed with the final users. Most environmental and natural resources data can only be recorded on the ground, but in many developing countries gathering ground data and collecting field samples is often the critical point.

In many developing countries legal and authority problems are increasingly limiting the possibilities of collecting data. Illegality and conflicts impede the establishing of land and natural resources uses according to social rules and law. Logistic problems sometimes limit the possibilities of implementing sound sampling schemes for collecting field data and reduce the possibilities of gathering information over large areas, controlling collected data and implementing management plans. Video remote sensing or small photographic cameras for checking and stratifying satellite image interpretation can substantially reduce the amount of field work, but military restrictions on flying and operating limit, in most cases, the release of images and delay data collection (Schade 1989, Jano,1986, Stellingwerf 1986).

Economic obstacles and lack of financial resources are major issues for remote sensing technology transfer in developing countries. These include (Yapa 1991, Yeh 1991, Saunders and Culter 1994, Youssef et al. 1980):

- high cost and lengthy procedures to obtain digital data (CCT's) and processing equipment (hardware/software)
- lack of foreign currency to import remote sensing products, equipment, and

technical assistance, and to guarantee adequate training programs

- lack of funding from developed countries to implement and maintain GIS systems with a sufficient operability over time.

The transfer of remote sensing and GIS technology to developing countries requires several socio-cultural conditions, including social stability, farsightedness, professional labour force and intellectual adaptability (Youseff et al. 1980, Voûte 1982, United Nations 1982). Educational, political, social factors affect the possibility of implementing these technologies. To the institutional problems and weakness of the social structure we should also add the insufficient international cooperation and the uncertainties about the future use of remote sensing and GIS technologies. Various measures have been suggested to overcome these obstacles (Madrid 1991, Nairobi 1993), but the challenge still remains "to demonstrate that the benefits of remote sensing technology applications outweigh their cost" (Specter 1988), to assess its real performance at national and local level, for planning and managing natural resources in a sustainable way, integrating remote sensing data with ground, and making effective use of collected information to curb unsustainable use of natural resources and environment.

The new inventorying and monitoring techniques are usually acquired by research institutions or forest organizations having limited possibilities of implementing and applying them in operational forest management programs. In many developing countries insufficient cooperation and inadequate information exchanges between research institutions and forest administrations do not allow researchers to evaluate the effectiveness of new forest techniques, neither does it allow an improvement of the professional attainments of officials. Researchers very often establish their programs independently from the services and the local organizations. Even knowledge and information flow among research institutions and between scientific organizations and professionals is lacking, and therefore any possibility to assess the real utility and effectiveness of new technologies for a sustainable use of natural resources is practically non-existent. The traditional forest management, focused on revenue generation through maximization of timber production, has alienated forest communities from both the forest resources and the Government's institutions and therefore institutional changes in the forestry institutions are required as well as a new participatory policy of local communities to protect and manage natural resources (Raju 1994). The development and implementation of forest management and protection plans should be carried out with the active participation of local communities, as they are the real actors of sustainable use of forest and natural resources. However they will support monitoring activities, new forest management systems, and new technologies for using natural resources as long as the marginal benefits obtained outweigh the costs of new technologies.

The data collected by remote sensing, GIS, and other new techniques for measuring and monitoring forest and environment are of limited use for management purposes, if we do not have a complete overview of the total system and we do not include the human element, as principal actor in changing the environment and transforming natural ecosystems. Therefore in our monitoring and inventorying programs we must include activities to assess the production systems, in order to correlate primary production and utilization and to ensure "that the information produced reflects actual conditions, not policies to protect influence, power, and territory" (Gay 1989). We should also foresee how our activities of collecting data or applying new technologies for natural resources utilization are perceived by governments, organizations and different social groups. If new monitoring technologies are perceived by local people as a means of enforcing centralized, bureaucratic utilization rules of forests and natural resources, and of restricting traditional land use rights, conflicts and opposition may arise between local communities and central authorities. On the other hand if global inventorying and monitoring programs are considered as a way of controlling the use of natural resources and a system to maintain the developing world in a subservient position, the chances of implementing successful programs in sustainable management at global, national and regional scale are minimal. "Understanding how people and organizations value resources and make decisions regarding the utilization and distribution of those resources helps us to know what to monitor" (Gay 1989) and also assists us to avoid conflicts, which could arise by undercutting values of some social groups while promoting interests of others (Alston and Freeman 1989).

An essential prerequisite for any effective intervention designed to improve the environment at local level is the integration of the data collected through conventional forest inventorying techniques with information on the uses and the production systems of local resources, and on the political, cultural and ethnological conditions of the region. Understanding the production system and its interaction with government agencies is the pre-requisite for the sustainable management of forest resources, as it can be achieved only with a direct involvement and motivation of local people, who should identify themselves with the development and protection of the forests they derive benefits from. Participatory approaches are required also to enable widespread adoption of sustainable practices enhancing feedback between specialists and forest dwellers, thus creating favorable learning environment. The success of any forest management or of any environmental project undertaken on the ground depends critically on real collaboration with local people and their inherent knowledge.

Traditional inventorying and monitoring systems focused on timber resources assessment need to be improved by taking into account non-timber forest produce (NTFP), ethnobiotechnical products, biodiversity, the production systems and their impact on different ecosystems. Compared with traditional timber utilization, sustainable forest management is more complex, more diverse ecologically and economically, more dependent on the beliefs, values and ethics of local dwellers. It requires more information than inputs of imported resources, it requires suitability to the needs, skills, training, and finances of land users, compatibility with the sociocultural environment and natural constraints (Campbell 1994). The traditional transfer technology model from science and institutional research to practice through extension needs to be revised giving more emphasis on knowledge processes occurring independently from institutions, and involving users in research and land use planning. The role of experts should shift from transferring information and products to facilitating knowledge processes (Ršling 1992) and the land users' role should change from validation of technologies developed in other contexts to the active participation in technology generation and natural ecosystems' management. Therefore higher priority should be given to the improvement of local practices and to a better utilization of locally produced biotechnological products, than to the import of technologies from industrialized world. The traditional "top-down" approach to resource management and to technology transfer needs to be revised and we should analyze more deeply under which circumstances local groups and individuals might engage themselves more actively in environmental management.

Developing countries have suffered not only from a heavy exploitation of natural resources and raw materials, but also from a continuous information drain which has not provided any benefit to the South but only a stronger cultural and economical subordination (Ibrahim 1992). Industrialized countries consider genetic resources and indigenous ethnobiotechnical knowledge as a "global commons" rather than regional resources and do not place any financial value on the maintenance of species-rich vegetation. The industrialized countries have the technical means to develop new technologies and new products and defend them by the Trade-Related Intellectual Property Rights of the GATT (WTO). For a sustainable management of tropical forests it is necessary that the profits arising from the use of these resources and indigenous technologies be shared with governments and peoples who have managed and cured them from time immemorial.

Conclusions

The transfer of any innovation is a complex operational system which needs to be well-planned, taking into account the positive and negative experiences carried out in similar social and environmental conditions in order to point out the critical moments, the obstacles or the opportunities to diffuse it. Handling remote sensing digital data in a GIS requires besides costly and complex equipment (computer hardware, application software modules) a proper organizational context, trained personnel, leadership, organization and funding. Lack of human and technical resources, weakness of forestry research institutions and the centralized bureaucratic services prevent an effective use of these technologies. Remote sensing data without sound ground sampling are of limited use for inventorying and monitoring forest ecosystem dynamics and do not provide reliable information on the impact of human activities on forest conditions. Additional research is needed on the application of remote sensing and GIS technologies applied to sustainable management of tropical forests, which requires a direct involvement of local people in the conservation of natural resources by sharing the benefits of a sustainable management of natural ecosystems. Forest dwellers and farmers should become integral part of the research process for setting up sustainable natural resources management plans and for developing new environmental technologies. The cultural and intellectual distance between those doing basic research and the final users, need to be filled by linking farmers and researchers activities and by developing intertwined operations for setting up correct management practices of natural resources. Non-Governmental Developing Organizations (NGDOs) can provide a substantial aid in getting local people to take responsibility for natural resources management and in promoting a participatory strategy to sustainable development.

More extensive and comprehensive studies on the information drain from developing countries are required in order to assess causes, dynamics and implications of genetic resources and ethnobiotechnological knowledge depletion. An increased commitment to share knowledge and research findings between developed countries and developing countries and within developing countries is essential, as synergism leads to cost-effective use of new technological tools, more efficient national and international cooperation, and a better education and training. Modern multi-media technology and computer networks make distance learning and information sharing easy and developed countries are committed to provide information management services and "distance-learning" techniques to the South cost free facilitating the access to common knowledge. This may lead to the institution of a global university for forestry (GUF), as proposed by Romeijn (1993), filling the information gap and making the cooperation between North and South more effective.

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DESIGNING A SAFETY NET IN THE CIRCUS OF NEW TECHNOLOGY

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Abstract

For a large scale inventory that must be useful for 10 to 20 years it is important to look ahead and use emerging technologies. Depending on that technology could be a disaster, an the other hand ignoring it could be short-sighted. If users are to take a change on moving into these new methods and techniques the inventory design must be set for alternatives to serve as backups for systems which could very well fail or stall the project at a critical time.

In the British Columbia Vegetation Inventory we have tried to look forward to tomorrow's technology, and at the same time we are keeping yesterdays techniques in the background. As Ronald Reagan would have said, we should "trust, but verify" this new technology. These tools are clearly very useful in principle, but the difficulty and number of practical details cannot be overlooked. If one of these newer methods fails, we have tried to set up another well defined path for the system. Where a new method is not well developed we have tried to plan for its' use at a later date.

Setting up alternatives in the inventory design will encourage the use and development of new techniques and instrumentation. Organizations are reluctant to risk the success of a large project on really new procedures. They are extremely cautious of methods not yet fully developed. This is not undue caution, it is wise project planning. If we can set up the technical safety net so that new technologies will not defeat the project then we can more easily introduce them into forest inventory.

Key words: Inventory design, technology, forest measurement

Almost 4 years ago I was asked to be the design specialist for the new British Columbia Forest Inventory. The area was 100,000,000 hectares (1/4 of a billion acres). This is nearly 3 times the size of Finland where this conference is being held. Some of the difficulties of scale will be obvious, especially since many of the areas are parks or wilderness with no simple access. From the first day, we were invited to imagine the uses for "new technology", and we certainly were inclined toward anything which would make life easier. I have a simple philosophy about inventory projects - I do not like failure. This is not to say that I do not like new ideas or new techniques, but they have an appalling failure rate. When enough time and money has been spent on new ideas, of course, they cannot be *called* "a failure" - but "interesting and instructive processes" do not please me much either. I am particularly drawn to a comment by Gene Woolsey in his editorial policy for the journal *Interfaces.* It discusses his *requirement* that authors demonstrate the financial savings of the project before it would be published. He states: "Assertions that the customer 'felt better' after the work was completed will be treated with the humor they deserve, and submitted to the *American Journal of Psychology*" (Woolsey 1976).

We had a large number of problems to solve, a limited number of opportunities for testing, and great expectations by all kinds of people that knew nothing about inventory. Large projects like this are similar to learning a new trapeze trick.

Rule 1: Do not work without a net!!

This is particularly important when your equipment has a strong tendency to fail. My particular job in the new inventory process was the overall statistical design, and many people reviewed the details and specialized techniques. Even though I have a significant amount of practical field experience in forest inventory, there is nothing like doing this work on a daily basis. This is important if you hope to balance the effort involving highly detailed field work. We worked hard to obtain the time and commitment of a number of very practical and experienced people to sort out the fine details of the vegetation measurements. *There is no substitute for experience of this sort.* No matter who *plans* a new circus stunt we should remember that somebody has to go out and *do* it. We had better listen to those people.

Rule 2: If you are the one flying through the air, you are particularly aware of the net - people who watch are not nearly as concerned.

One of the problems with new technologies is that they are usually individual items (sometimes very clever ones), and inventories are *systems.* As with all systems, it is the balance and design that count, not individual parts that may delight or amaze you. It is not wrong to put jeweled bearings on wheelbarrows, but it is probably unwise and inappropriate - no matter how satisfying. A desirable goal of systems is to develop balance and depth in their design. The introduction of new technology usually works against this goal.

Consider, for instance, the introduction of personal computers to offices - a clearly appropriate move, no doubt about it. What did they forget? The first thing they forgot was that the mainframe organization backed up their data regularly. Individuals *do not* back up their work. The memos which were no longer held up by secretarial backlogs were also no longer filed for future reference. The bottlenecks that acted to hold up the paperwork were also one of the few sources for integrating what was going on in the building. In the end, even the floppy drives everyone used went out of style and often the data could no longer be read. *Scientific American* recently printed an article about how unlikely we are to be able to read computer storage media even in the relatively near future.

Did any of these things cause computers to fail ? No. The machines failed enough on their own in the early years. These problems caused *offices* to fail. Did we get these problems under control ? Almost, but not quite yet. Should we have gone to personal computers in the office place ? Most certainly, but many of the problems could have been foreseen, and let this be clear - they *were* problems. The goal was not to get computers to work - it was to get offices to work better with computers as part of that system.

With untried (and often failing) new technology the trick is to plan for its introduction when it eventually *does* work, using training to emphasizes the principles it will introduce. You want people to automatically think along those lines when the time comes. We need enough pilot testing to work out the problems of how it fits into the organization, the information flow, and the documentation procedures. In my opinion, we can expect to go through at least one full set machines for a new technology before we learn how to *think* about the techniques and how to control them. Therefore, the major emphasis in adopting a new technology is not "how to make it work", because it will almost never work well enough initially. The major emphasis should be "how do we *think* about this, how will we fit it into our business, and how will we transfer the data to the next machine?".

In addition, I believe that we need to *plan* for failure in new technology. There are two reasons for this. The first reason is that it does the project no good to fail (even partially) because of a new technology. The solution for this seems clear to me. Have a backup for most of the systems in an inventory scheme, and particularly for those involving new technology. When it is likely (not obvious) that these systems are undermining the success of the project, switch to the other method as the main thrust (but keep working on the newer method). In this way you take the pressure of time off the new technology that you need to develop. Too much pressure seldom helps the development of a new technology. There is a tendency to ignore the overall process while you are just trying to get the mechanical aspects of a single part working.

The second reason to anticipate problems is that a record of failure is not good for a new technology. It sours the bystanders on the concept when the real failure was often just the execution or the timing. People remember a bad taste long after the problem has been fixed. New technology requires testing and a certain amount of patience and tolerance - not only to make it function, but to take the time to fit it into the business.

Certainly, the premier current example must be the use of Geographic Information Systems (GIS). They are so clearly a correct idea, and so clearly a disaster over the last few decades. Now that the machines really have the power they need, the software could really be written, and the need is becoming urgent, have we really learned how they fit into the process? I would suggest that we have learned very little.

I believe that we have managed to succeed with another technology, the Global Positioning System, for one simple reason. We knew exactly what the question was ("Where am I?"). With GIS we have simply not sorted out the questions. The sellers believe that the answer "is GIS", but are not sure what the questions are. Too much emphasis is on making it work, too little on asking the fundamental questions. It would be a shame if this goes on much longer, because this kind of failure is not good for anyone.

Rule 3: Until the new stunts work, use the old ones.

Some low tech safety nets

For the purpose of this discussion, I include the use of new sampling systems and other ideas, because new technology is just one instance of the same problem - introducing needed but untried change into a processes. "New" to one organization, or course, may be old hat to another one. As background, the new inventory design for British Columbia is a simple adjustment scheme where estimates initially made on all vegetation polygons are sorted into a list, sampled systematically, then adjusted based on the ground measurements.

Estimated polygon values & photointerpretation

Like everyone, we have heard promising comments about automated, space-based estimates for polygon features. We have done less to explore these that I would wish, but in the end we are prepared to bring out the simple stereo viewers, sit down legions of photointerpreters and do the job the long hard way. We believe that automated systems have a long way to go, and trying to do them with satellites just makes the job that much tougher. We are dealing with a situation where we have a good many photointerpreters available in British Columbia, but the expense for this will be large. If this system fails, because of elapsed time or from expense, then we are willing to use our old maps (with their estimates of volume, for instance) as the first stage for the new inventory.

Coordination

Interlocking systems are a guarantee of trouble. As far as possible, we have uncoupled the processes carried out on sample locations. This is done for two reasons. First, it allows groups working on individual problems to proceed with that work at their own pace. What little we lose in efficiency here is well worth the cost. The reduced pressure on each of these groups is a great advantage. Second, if some of this information simply is not worth the cost at each sample location then the procedure can take place on some proportion of the locations. Having too many processes coupled together increases tension, increases the chance of delay or failure, and I believe that it will eventually increase cost - no matter what the claims of efficiency might be. If some of the groups fail, they are simply left behind while other groups move ahead.

Compilation

There is no way that every compilation can be agreed upon before the inventory and fully tested. Even if that were possible, someone would soon change a site index curve and want to apply it. The raw data is stored close to its original format. Standard calculations (such as tree volume) are added back into the raw data, so they become available without repeated computer processing.

Data storage

Hard copy - period. The original cards can easily be stored, of course, but we plan on printing out a copy from the computer records in the same format for comparison. Again, all the computer records are to be produced on paper. "Paper lasts" - there is a long history for this statement. I simply do not believe that the data is safe "out there in electromagnetic space", no matter what the computer jocks may believe. We will, of course, plan to use on-line databases, but we assume that there will be a disaster or at least a need to show that a disaster did not happen. I remember a computer programmer once telling me that he might have changed a set of data "to metric" twice, many years ago, but he was not sure. There were no records to check. Hard copy - period !!

Sampling design & credibility

If all else failed, we could simply compute a simple average from our sample. We believe that much more sophisticated use of the data will be made, but this simple approach remains open to us. If a simple calculation is all that a reviewer will believe, then we will be prepared to furnish the answer in this way. For the most part, the proposed statistical methods have a long history, backed up by publications and experience. Only the combination of parts is in any way unique, like much of new technology.

Quality control

Someone can always make mistakes or at least commit outright fraud. For this reason, there is not only the usual quality control check within the system, but the system is being designed for a formal outside audit. This will allow the people of British Columbia the option of an outside agency to assure them that the overall answers are roughly correct. We will not depend upon honesty and correct data - although we expect it. It has been suggested that we should be able to generate a valid sample plan for any outside agency who wishes to check the answers on any attribute of the inventory.

Direct overall measurements

There are many assumptions, tables and studies used by the inventory. We expect that all of them will be reasonable and as correct as we can make them. We may use high tech measurement systems to measure upper stem diameter or taper. In the end, however, we will fall trees and measure them on the ground. The attempt here is to wrap as many possible problems as we can into one bundle and check them all at once.

Remeasurement

We do not particularly plan to remeasure the plots. Nonetheless, we are able to this if it is necessary or desirable. The locations are noted on the photos, the maps, and by UTM coordinates. There will undoubtedly be someone who wants to revisit them, if only to subsample the data for quality control. The sample locations are a valid sample of the land base in the entire province, not just for vegetation samples.

Evaluating new technology

When I am told about the merits of new technology I take a pretty simple approach. I begin by assuming that I am the potential victim, and therefore I am the one who takes the fall. A surprising number of people do not do this. I ask roughly the following questions, tailored to suit the particular technology.

1) How will I know when it fails ?

If the answer is "it just will not" or "we have to be optimistic" or (the very worst) "there is no way" then the discussion is terminated. Anyone who cannot figure out how to recognize failure is not likely to do me much good.

2) What happens when this is (broken, stolen, not responding) ?
If the whole system must stop, then I am immediately concerned. Count on it - it will break. At the very least I prefer technology which is developed for lots of work in parallel, rather than a lineal system where stopping one part of the system stops everything. In every case, the person in the field needs a backup plan.

3) Who do I call on Sunday at 3:00 in the afternoon when I have a problem ?
This usually causes a nervous giggle as the first response. My own view of most software, for instance, is that the programmers home phone number should be displayed with every system error message. Better yet, a beeper. The acid test : "Get them on the phone, right now ... I'll wait".

4) Tell me the name of a client who will swear that this works well.
In this instance I want the name of the guy his company will call at 2:00 in the morning when the panic is on, not some vice-president who knows next to nothing about the details (and does not know the answer to question #1). This is also the first person I would talk to about who to hire, so that I do not have to repeat the nasty and expensive lessons of adopting this technology.

5) What is it that the business really needs, beyond this particular solution ?
I want to talk with someone who knows where we are going, and roughly how we might get there. If the answer is "Oh, well this is just simply IT", then the discussion is terminated. This person knows no more about the directions of the business than the people pushing the old solutions. At this point, it usually becomes clear that they do not know what is currently done either.

Conclusion

All things considered, I am a great fan of new technology. I believe, however, that the big gains are to be made by systems which show balance, backup and flexibility. These kinds of systems should give us enough slack to develop new technology and enough time to introduce the principles they represent into the thinking of our profession. That time and tolerance would do a lot to insure that new technology does not get an unfairly bad reputation, and that any failures are just part of the business - not the end of it.

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FOREST RESOURCE MANAGEMENT PLANNING UNDER FUZZY DECISION ENVIRONMENTS IN TAIWAN

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Abstract

Since the multiple-use of forest concept emerged, the problem faced by management planning is how to settle conflicts on land use. Goal programming that includes a set of quantitative goals may be used for the determination of forest management activities. This method is a modification and extension of conventional linear programming. Goal programming seeks a plan that comes as close as possible to attaining specified goals. The flexibility of this method allows the specification of a problem in terms of multiple conflicting goals and the allocation of resources according to subjective priorities. It also offers a method for analyzing the use of interactions to determine quantitative expressions for complementary and competitive influences. Furthermore, forest systems are inherently complex and therefore lend themselves naturally to fuzzy approaches in management planning. This paper describes the technical aspects of goal programming under fuzzy decision environments. A solution approach based on linear programming is developed. A possible application to a problem of forest management planning in Taiwan is presented.

Key words: Resource allocation, fuzzy sets and systems, fuzzy linear programming, fuzzy goal programming

1. Introduction

Forest resource management planning is the guiding line for scheduling and executing various activities in the forests. It is also the art and science of making decisions with regard to the organization, use, and conservation of forests. The problems of forest management planning arise when decisions are made about how the forest relates to human needs.

Recently, as the amount of timber and forest-related products have increased according to economic growth and science development, the importance of forest production has been recognized; simultaneously, nature conservation is of concern to the general public. The forest management objective has been changed from the mono-use of increased timber production to multiple-use of improved water quality, protection of wildlife, and increased recreational opportunities. Furthermore, forest ecosystem management while maintaining biodiversity must be included. Forest management planning problems are complex or wicked (Allen and Gould 1986). There are also possibilities of conflict between objectives. We should try to manage the forest resources towards all objectives attaining simultaneously a satisfactory level of achievement.

Forest regulation is perhaps the most important objective of forest management planning. The reason for the approaches to forest regulation that have been used by foresters since the nineteenth century, was to secure regular annual yields from a forest. It is essentially a scheme of management aimed at controlling forest activities which are to carry out forest policy. The traditional forest regulation has been applied by the various forest managers of Germany, France, Japan, China, and other countries. Foresters then used a variety of formulas and procedures to convert the current forest into a desired regulated forest, that is a so-called normal forest. The traditional regulation techniques employed biological measures of the forest, such as inventory volume and growth, in the decision guides, leaving economic consideration almost wholly aside.

The older methods of forest regulation have become obsolete. A few of the reasons can be mentioned. Today, with no fear of impending timber famines in any particular area, strict regulations on the annual and periodic cut is not necessary. Continuously changing economic conditions have clearly shown that forest regulation cannot look ahead too far into the future. Moreover, multiple-use of forest has arisen and the demand for environmental services of forests is growing rapidly as population and income per capita increase.

In view of the inherent complexity of the forest management problems, mathematical programming techniques have replaced the traditional formulas used in early years of forest regulation. Now, the general public is interested in forest management activities for timber, amenity, and other purposes. Therefore, mathematical programming has been transported and adapted to forest regulation to help with quantification, explanation, and justification (Davis and Johnson 1987). This may be another reason which explains why the mathematical programming techniques have been adopted today.

The forest management problem is complex and uncertain because of the diversified nature of the forest itself as well as because of the different biological, physical, and economic processes inside and outside the forest ecosystem. Fuzzy approaches, therefore, are naturally incorporated in planning and decision making.

The purpose of this paper is to examine the use of mathematical programming in forest management planning problems under fuzzy decision environments. We will consider the technical aspects of the model, the published records of its use to date, and an example of its application to a forest management planning problem in Taiwan.

2. *Linear programming and fuzzy linear programming*

Linear programming model focuses on the problem of determining an optimal allocation of scarce resources. In a conventional linear programming (LP) problem:

$$\text{Max } Z = cX \quad (1)$$

$$\text{s.t. } AX \leq b \text{ (2)}$$

$$x \geq 0$$

where A, b, and c are fixed coefficient matrix and vector. Similarly, the objective function is to strictly maximize Z = cX, while the constraints are also to be satisfied in a strict sense.

To treat ambiguous phenomena, Zadeh (1965) extended the concept of common sets into the concept of fuzzy sets. In a fuzzy set, the degree of an object conforms to some attribute which may be represented by membership function. This function is analogous to, but really is not, a frequency distribution. The probability theory is appropriate for measuring randomness of information; it is inappropriate for measuring the meaning of information. Zadeh (1983) proposed the possibility theory as a measure of vagueness, just as the probability theory measures randomness. In reasoning about uncertainty, one can use fuzzy set to quantify the extent to which a proposition is true. Under a set membership function, an individual can take on a real value between 0 to 1. When it is close to 1, it means that some attribute to which an object belongs is extremely great. Bellman and Zadeh (1970) provided the pioneering work in incorporating fuzziness in the context of crisp mathematical programming and decision making.

If the decision is to be made under a environment, the objective function and constraints are not distinctly identified. The decision maker may desire to achieve some aspiration level for the objective and tolerate small violations in the constraints. Under the fuzzy circumstances, the conventional linear programming problem in Equations (1) and (2) can be stated as:
Find X such that

$$cX \gtrsim Z_0 \quad (3)$$

$$AX \lesssim b_0 \quad (4)$$

$$x \geq 0$$

The symbols "$\gtrsim$" and "$\lesssim$" are the "fuzzifier" which represents essentially larger and smaller than or equal to Z_0 is an aspiration level for the objective function and b_0 is tolerance levels for the constrains.

3. *Goal programming and fuzzy goal programming*

Goal Programming is a modification and extension of linear programming. The goal programming is a mathematical procedure which provides a simultaneous solution of a system of complex objectives. In a conventional goal programming (GP) problem, the "decision" is to optimize the multiple objective functions within the constraints imposed by the decision environment. Both objective functions and constraints are formulated precisely.

If the decision of goal programming is to be made under a fuzzy environment, both objective functions and constraints enter into the expression for a fuzzy decision D in precisely the same manner. Since the decision D is defined as a fuzzy subject, the compromise decision is any alternative $x \in X$ that maximizes the membership function for decision set μ D(X).

Using the definition of a fuzzy decision, the membership function of the decision μ D(X), is given by

$$\mu_D(X) = \mu_1(AX)\mu_2 \cap \ldots \cap \mu_m(AX)$$
$$= Min\ \mu_i(AX)$$

and the maximizing decision is given by

$$Max\ \mu_D(X) = \underset{x}{Max}\ \underset{i}{Min}\ \mu_i(AX)$$

The decision in a fuzzy environment can therefore be viewed as the intersection of fuzzy constraints and fuzzy object function (Zimmermann 1978). The fuzzy goal programming formulation represented by equation (7) may be difficult to solve in general. However, if the membership functions are linear, then the problem can be solved easily by linear programming methods.

4. *Literature review*

In Taiwan, forestlands produce many commodities and services that are valuable to society. The societal concerns to forest management activities have become extremely intensive. Now, the techniques for multiple-use forestland management planning are complex. Within this new context, mathematical programming has replaced the simple formulas for forest regulation used in early years for analysis and planning. Mathematical programming for solving management problems in which several objectives are considered simultaneously. It should not be used to look for the answer, but rather to focus on the problem in order to better understand forest management.

Linear programming was introduced as a technique to solve problems that are related to forest regulation since the early 1970's. A variety of useful and creatively titled computer programs such as RAM, SIMAC, MUSYC, FORPLAN, etc. have been developed to assist this effort.

Yang *et al* (1968) provided the pioneering in the extension of linear programming on forest regulation problems in Taiwan. The forest planning problem considered is adapted from a case study of the Experimental Forest of National Taiwan University. A computer program based on the simplex method was written by themselves to solve all linear programming problems involving up to 20 constraints and 50 variables.

In 1978, zero-one integer programming was examined in terms of their properties and underlying mathematical structure (Yang *et al*). A case study for the preparation of timber harvesting planning under this mathematical programming was presented.

Timber RAM (Navon 1976) is a computerized method for preparing forest management planning. Under the consideration of multiple-use and various constraints, which include biological, economical and policy factors. The Mu-Kau National Forest was selected as a case study to demonstrate the feasibility of this method in Taiwan (Yang *et al* 1981).

The applicability of goal programming to multiple-use forest resource management planning in Taiwan was described by Yang (1992). A solution approach based on the simplex method of linear programming was developed and this approach was extended in the case where cardinal and ordinal weights were associated with multiple goals.

Over the years, the presence of a fuzzy environment and a variety of forest management planning problems have been recognized. Several methods have been proposed as suitable planning tools for a solution. The most notable of these studies are briefly introduced. In recognition of the inherent complexity of forest systems, Mendoza and Sprouse (1989) used fuzzy goal programming for solving this problem. Two modeling approaches were proposed: (1) generation of alternatives, and (2) evaluation and prioritizing of these alternatives. Their methods were verified when dealing with a multiple-use planning problem concerning a national forest in the United States. These methods are considered appropriate for fuzzy decision environments.

To cope with the fuzzy environment of timber harvest scheduling in the United States, Mendoza and Bare (1990) proposed fuzzy linear programming to optimize the management objective and to meet the constraints. Two analysis areas which represent a typical American national forest were presented to demonstrate their approaches. They concluded that fuzzy methods are viable planning tools for situations which involve incomplete data and insufficient information. In light of being difficult, fuzzy linear programming deserves additional study.

Nogami (1990a) recognized that because of the complicated problems of forest management planning, the optimum solution to a mathematical model and the optimum solution to the planning problem may not be the same. He used the fuzzy approach to the linear programming to formulate the problems of yield regulation. It contains fuzzy constraints and a fuzzy objective. He also used the fuzzy approach to the HSJ (Hop, Skip and Jump) method to generate planning alternatives that are good with respect to the modeled objectives, but widely different from each other in decision space (Nogami 1990b). The forest manager can choose the one that is most suitable. The fuzzy linear programming problem can be transformed into a conventional linear programming problem for easy calculation.

Bare and Mendoza (1992) described a fuzzy approach for explicitly recognizing the imprecise nature of the harvest flow constraints usually included in harvest scheduling models. Satisfactory solutions were derived and discussed. An illustrative sample problem was presented to demonstrate the methodology.

More recently, fuzzy goal programming to forest management decision-making has drawn the attention of foresters in Taiwan (Yang *et al* 1995). A multiple-use example based on the Experimental Forest of National Taiwan University was used to test various fuzzy-modeling approaches. Results show that fuzzy-based solutions offer the decision maker superior solutions with a wider range of choices than do those based on linear programming.

5. *Method*

All models are abstractions of reality, and hence are subject to formulation errors. To help mitigate against the consequences of adopting solutions from inadequately formulated models, Brill *et al* (1982) advocates the modeling to generate alternatives (NIGA) method which is called HSJ for Hop, Skip and Jump. It generates alternative solutions that are satisfactory with respect to the objectives and maximally different with respect to the decision. Some insights may be gained, particularly on issues and concerns that may not have been initially considered in the model. The steps in the HSJ approach, in its simplest form, are discussed briefly below:

Step 1. Obtain an initial solution by any method.

Step 2. Obtain an alternative solution by solving:

$$Min = \sum_{j=1}^{J} X_j \tag{8}$$

$$s.t. \quad Zk(X) \geq Tk;\ k = 1,2,\ldots,k \tag{9}$$

$$x \in X \tag{10}$$

where

J = set of indices of the decision variables that are nonzero in the initial solution.

Tk = target specified for objective Zk(X).

X = set of feasible solutions based on the technical constraints of the model.

Xj = basic Variable j.

The formation is designed to produce an alternative solution that is different from the first one by minimizing the sum of the decision variables. The targets specified ensure that the alternative solution will be satisfactory with respect to modeled objectives.

Step 3. Generate a third solution that is different from each of the first two.

Step 4. Generate a series of additional alternative solutions by continuing the process.

The HSJ procedure is stopped when no new decision variables enter the solution because all decision variables are included in the current HSJ objective function.

The HSJ algorithm is very flexible and lacks the rigid structure and systematic procedural search of other algorithms. The specific procedures of MGA reflect an appreciation of the limitations of formal mathematical models for planning and policy analysis. In general, the HSJ method may be useful in many problems for generating alternative solutions that are different from each other.

Mendoza et al (1989) developed a fuzzy approach of NIGA to produce solutions extends in two major areas: (1) flexible generation of distinct alternatives by specifying a wider range of differences in solutions, and (2) generating satisfactory alternatives where the target level for each objective are expressed in an interval rather than a single value.

The fuzzy mathematical programming formulation of MGA, based on equations 3-4, can be expressed as:

Find a solution X, such that

$$S^{I} \le \sum_{j \in J} Xj \le S^{II} \tag{11}$$

$$Zk(X) \ge Tk;\ k = 1,2,\ldots,p \tag{12}$$
$$x \in X$$

where S^{I}, S^{II} are the lowest and highest value of the surrogate measure of difference between two generated solutions; J is an index for all basic variables; and T_k are the target levels for objective *k*. Note that in the traditional MGA formulation, the sum of the basic variables is to be minimized. Hence, maximally different solutions are generated. The formulation in Equation (11) allows the generation of widely different solutions where the difference of these solutions is approximately within the level specified by S^l and S^u.

Before presenting the crisp mathematical model of (11) to (12), the membership functions must be explicitly stated. The membership function for (11) following its basic form is:

$$m_{(11)}(X) = \begin{bmatrix} 1 & \text{if} \sum_{j \in J} X_j = S^l \\ \left(S^u - \sum_{j \in J} X_j\right) \Big/ \left(S^u - S^l\right); & \text{if } S^l \le \sum_{j \in J} X_j \le S^u \\ 0 & \text{if} \sum_{j \in J} X_j > S^u \end{bmatrix} \quad (13)$$

Likewise, the membership function for (12) is:

$$\mu_{(12)}(X) = \begin{bmatrix} 1 & \text{if } Z_k(X) = Z_k^0 \\ 1 - \left(Z_k^0 - Z_k(X)\right) \Big/ \left(Z_k^0 - Z_k^p\right) & \text{if } Z_k^p \le Z_k(X) \le Z_k^0 \\ 0 & \text{if } Z_k(X) \le A_k^p \end{bmatrix} \quad (14)$$

where

Z^0_k = an optimistic target value of objective k,

Z^p_k = a pessimistic value of objective k.

The Crisp Mathematical programming model for the fuzzy MGA given (13)-(14) can be stated as:

$$Max\ \lambda \quad (15)$$

$$s.t. \quad (S^u - S^l) + \sum_{j \in J} X_j \le S^u \quad (16)$$

$$-(Z_k^0 - Z_k^p)\lambda + Z_k(X) \ge Z_k^p; \quad k = 1,2,\ldots,p \quad (17)$$

$$x \in X$$

The optimistic and pessimistic values of objectives k may be specified at some values based on initial estimates. For instance, the maximum value may be used as the optimistic value, while the minimum value may be used as the pessimistic value. The formation in Equations (15)-(17) was used in a land-use planning study by Chang et al (1983).

6. *Applications in Forest Resource Management Planning*

To illustrate the potential usefulness and limitations of the fuzzy decision models described in the previous section, a multiple-use forest resource management planning problem is presented and analyzed.

The forest tract with an area of 1,361 ha is located in the Experimental Forest of National Taiwan University (T.U. 1990). The problem involves the allocation of forest lands to various land uses. Four objectives are considered: (1) maximize the timber yield, (2) maximize the soil water production, (3) maximize the area suitable for forest recreation. and (4) maximize the area suitable for wildlife habitat.

Recent developments in forest resource management provide a way to deal with multiple objectives. But in fact, the nontimber objectives cannot be disassociated from standing trees. For example, the forest recreation can bring a large amount of monetary income. Nevertheless, the number of visitors decreases with the decreasing amount of forest area and timber growing stock. The soil water production can be enhanced by healthier trees in the forest. Total timber volume and an equal area in each age class are the best indices to represent the "healthiness" of a forest. Therefore, in this research, although four management objectives were set, we still think the maximum timber yield is the most important one.

A planning horizon of 30 years is decided up and is divided into three 10 year planning periods. The following assumptions are used in the model formation:

(1) The basic point of calculation is at the middle of a planning period.
(2) Planning is done immediately after harvest.
(3) The forest growth rate follows the yield table (T.U. 1990).
(4) The old forest must be harvested and the young forest must be left.
(5) Thinning is done between ages 20 and 30.
(6) If the timber land is harvested and is transferred for recreation use or wildlife habitat, it will never be used for timber production.
(7) The land for original state without any timber production or recreation activities.
(8) The soil water storage capacity is evaluated by each age class (Chen et al 1986).

The mathematical model is formulated as follows:

Objective functions:

$$Max\ Z_T = \sum_{i=1}^{3}\sum_{j=1}^{5} V_{ij}(X_{ij} + RX_{ij} + BX_{ij}) + \sum_{i=1}^{3}\sum_{j=1}^{5} TV_{ij} \cdot TA_{ij} \tag{18}$$

$$Max\ Z_W = WF_{ij}\left[AT - \sum_{i=1}^{3}\sum_{j=1}^{5}(X_{ij} + RX_{ij} + BX_{ij})\right] + \sum_{m=1}^{3-i}\sum_{i=1}^{3}\sum_{j=1}^{5} WR_{ijm}(X_{ij} + RX_{ij}) + WN\left[\sum_{i=1}^{3}\sum_{j=1}^{5} BX_{ij} + (X_{35} + RX_{35})\right] \tag{19}$$

$$Max\ Z_R = \sum_{i=1}^{3}\sum_{k=1}^{3} R_i Y_{ik} \tag{20}$$

$$Max\ Z_B = B + \sum_{k=1}^{3} B_i \tag{21}$$

Constraints:

$$\sum_{j=1}^{5}\left(X_{1j} + RX_{1j} + BX_{1j}\right) = \sum_{j=1}^{5}\left(X_{2j} + RX_{2j} + BX_{2j}\right) = \sum_{j=1}^{5}\left(X_{3j} + RX_{3j} + BX_{3j}\right) \tag{22}$$

$$\sum_{j=1}^{5} X_{1j} = \sum_{j=1}^{5} X_{2j} = \sum_{j=1}^{5} X_{3j} \tag{23}$$

$$X_{ij} + RX_{ij} + BX_{ij} \le A_{ij} \quad i = 1,2,3; \quad j = 1,2,3,4,5 \qquad (24)$$

$$\sum_{i=1}^{l} \left(X_{i,i+5-l} + RX_{i,i+5-l} BX_{i,i+5-l} \right) = A_l; \quad l = 1,2,3 \qquad (25)$$

$$Y_{ik} - Y_{i-1,k} \ge 0 \qquad (26)$$

$$\sum_{k=1}^{3} Y_{1k} \le 450 \qquad (27)$$

$$\sum_{k=1}^{3} Y_{2k} \le 500 \qquad (28)$$

$$\sum_{k=1}^{3} Y_{3k} \le 800 \qquad (29)$$

$$\sum_{i=1}^{3} \sum_{k=1}^{3} L_{ik} Y_{ik} = 50{,}000 \qquad (30)$$

$$\sum_{k=1}^{3} Y_{ik} - \sum_{k=1}^{3} Y_{i,k-1} = \sum_{j=1}^{5} RX_{ij}; \quad i = 1,2,3 \qquad (31)$$

$$\sum_{i=1}^{3} B_i \le 30 \qquad (32)$$

$$B_i - B_{i-1} \ge 0 \qquad (33)$$

$$B_i = \sum_{j=1}^{5} BX_{ij}; \quad i = 1,2,3 \qquad (34)$$

$$\sum_{j=1}^{5} CT_i A_{ij} + \sum_{k=1}^{3} CR_i Y_{ik} - \left(CT_i + CR_i - CO_i \right) OA \le C; \quad i = 1,2,3 \qquad (35)$$

where

ZT, Zw, ZR, ZB = objective functions representing total timber yield, soil water storage capacity, recreation visit-days, and wildlife habitat, respectively.

V_{ij} = final cutting volume per hectare in period i and in age class j.

X_{ij} = hectare of land harvested and planted in period i and in age class j.

R_{xij} = hectare of land harvested in period i and in age class j, then this land is transferred for recreation use.

B_{xij} = hectare of land harvested in period i and in age class j, then this land is transferred for wildlife habitat.

TV_{ij} = thinning volume per hectare in period i and in age class j.

TA_{ij} = hectare of land thinned in period i and in age class j.

R_i = recreation visitor-days per year per hectare in period i.

Y_{ik} = recreation area in period i and in compartment k.

B = original wildfire habitat area.

B_i = increased Wildlife habitat area in period i.

AT = total land area.

WF_{ij} = soil water storage capacity of forest trees in period i and in age class j.

WR_{ijm} = soil water storage capacity of forest trees after m's planning period of regeneration.

WN = soil water storage capacity of cutting area without regeneration.

A_{ij} = available cutting area in period i and in age class j.

A_l = available cutting area in all periods.

L_{ik} = meters of trail length per hectare in period i and in compartment k.

CT_i = cost per hectare for managing timber land in period i.

CR_i = cost per hectare for managing recreation land in period i.

CO_i = cost per hectare for managing both timber and recreation land in period i.

OA = hectare of land for both timber and recreation use.

C = total cost, budget constraint.

In formulating the goal programming problem, the decision variables represent hectares of timber harvest, forest recreation, and wildlife habitat. Constraints (22) to (25) are area constraints about nondeclining yield. While constrains (26) to (31) denote recreation. Decision variables for wildlife is illustrated in (32) to (34). Constraint (35) limit the cost for both timber and recreation. There is no cost for managing wildlife habitat. Soil water storage capacity is included in the formulation through equation (19).

An initial solution of the MGA method was obtained by solving the original multiobjective goal programming. The values of the solution are given in table 1 containing the maximum values of the four objectives when they are optimized independently.

Table 1. Maximum and attainable values of each objective when maximized separately.

Solutions	*1*	2	3	4
Timer	152797.2	150595.9	149913.5	147190
Water	839200.6	862992	842477.3	956995
Recreation	33148.73	32480.28	33148.73	31245.33
Wildlife	161	154.87	161	161

Following the steps of the algorithm as described earlier, the solution that maximized the timber yield objective is chosen as the initial alternative in Step 1. This alternative yields 152,797.2 m^3 of timber; 839,200.6 t of soil water; 33,148,730 vd of recreation, and 161 ha of wildlife habitat.

For step 2 of the algorithm, the targets levels are: 150,000 m^3 of timber, (2) 830,000 t for soil water, (3) 30,000,000 visitor-day of recreation, and 100 ha of wildlife habitat.

The basic variables from the initial solution in Step 1 are identified and included in (8). The solution generated in Step 2 is denoted by HSJ1 in table 2. Again, the basic variables from the HSJ1 solution are identified and included in (8) to generate the next solution, denoted by HSJ2. The process is repeated as other alternatives are generated. A summary of the HSJ solutions generated for the application problem are given in tables 2 and 4.

Table 2. ***Objective function values generated by HSJ methods.***

	INITIAL	HSJ-1	HSJ-2	HSJ-3	HSJ-4	HSJ-5	HSJ-6
Timber	152797.2	150000	150000	150000	150000	150000	150000
Water	839200.6	840000.3	848917.4	848843.4	844901.4	850519.4	850151.4
Recreation	33148.73	33148.73	30837.33	30837.33	30837.33	30837.33	30837.33
Wildlife	161	161	161	161	161	161	161

The result described in tables 2 and 4 are extensions of MGA and are designed to generate distinct solutions. It shows the HSJ method can be used to generate numerous alternatives that are good with respect to the objectives. In using the HSJ method, the objectives are constrained to meet targets, but it may not be easy to determine the proper levels for them. The concept of fuzziness can, therefore, be applied to the MGA framework for generating planning alternatives that are good and different. Fuzzy approaches can be used to increase the flexibility of targets on objectives as well as the flexibility of the constraints.

In the sample problem, under the fuzzy decision environments, the optimistic and pessimistic values for the four objectives are obtained from table 1. They are set as follows:

Timber:	152,797.2 ~ 147,190
Water:	892,992 ~ 839,200.6
Recreation:	33,148.73 ~ 31,245.33
Wildlife:	161 ~ 154.87

The fuzzy goal programming problem can be transformed into a conventional linear programming model. Based on equations (15)-(17), the fuzzy HSJ solutions generated for the application problem are summarized in tables 3 and 5.

Table 3. ***Objective function velues generated by the Fuzzy HSJ methods.***

	INITIAL	HSJ-1	HSJ-2	HSJ-3	HSJ-4
λ	0.818	0.694	0.67	0.699	0.696
Timber	151775.1	151083.2	150945.9	151108.7	151092.7
Water	858655.1	855719.6	855136.9	855827.9	859494.6
Recreation	33148.73	32566.91	32520.29	32575.57	32570.14
Wildlife	161	161	161	161	159.14

Fuzzy HSJ-4 is very satisfactory as reflected by no new basic variable can enter the solution, and the value of is relatively high. It provides satisfactory values for soil water storage capacity, but with a relatively poor satisfaction level for recreation and wildlife. It should be point out that in this solution, timber yield has priority over other objectives.

Table 4. Land use allocation generated by HSJ methods.

Solutions	*INITIAL*	*HSJ-1*	*HSJ-2*	*HSJ-3*	*HSJ-4*	*HSJ-5*	*HSJ-6*
no. of new basic vari.	25	9	1	1	1	1	0
X13		70.75					
RX13				2			
BX13			2				
X14	36.88		62.67	52.67	56	54.67	64.67
RX14	23.87				8.67		
BX14	10			10		10	
X15	87	53.13	70.33	80.33	77	78.33	68.33
RX15		23.87	8.67	6.67		8.67	8.67
BX15		10	8		10		10
X23					2		2
RX23		22.49					
BX23						2	
X24	123.88	41.88	113.67	113.67	123.67	132.33	122.33
RX24	22.62	1.38	8.67	8.67	8.67		
BX24		10	10	10			10
X25		82	19.33	19.33	7.33	0.67	8.67
RX25	1.25					8.67	8.67
BX25	10				10	8	
X33	9.12	2.88					
RX33		6.24					
BX33							
X34	30.12		21	31	29	10.33	10.33
RX34		17.63				8.67	8.67
BX34	10		10			10	10
X35	84.63	120.9916	112	102	104	122.67	122.67
RX35	23.87		8.67	8.67	8.67		
BX35		10			10		
Y11	60	60	60	60	60	60	60
Y21	60	60	60	60	60	60	60
Y31	60	60	60	60	60	60	60
Y12	150	150	158.67	158.67	158.67	150	150
Y22	150	150	158.67	158.67	158.67	150	150
Y32	150	150	158.67	158.67	158.67	150	150
Y13	223.87	223.87	200	200	200	208.67	208.67
Y23	247.75	247.75	208.67	208.67	200	217.33	217.33
Y33	271.62	271.62	217.33	217.33	208.67	226	226
B1	10	10	10	10	10	10	10
B2	10	10	10	10	10	10	10
B3	10	10	10	10	10	10	10

Table 5. Land use allocation generated by Fuzzy HSJ methods.

Solutions	*INITIAL*	*HSJ-1*	*HSJ-2*	*HSJ-3*	*HSJ-4*
no. of new basic vari.	*26*	*8*	*3*	*2*	*0*
value of fuzzy object	*0.818*	*0.694*	*0.67*	*0.699*	*0.696*
X13				5.48	
RX13			7.67		
BX13				3.18	
X14	60.75	49.17	40.62	35.49	43.87
RX14		20.05	19.96	23.87	23.87
BX14	10				
X15	63.13	77	87	87	84.51
RX15	23.87				
BX15		10			2.49
X23	10.2	24.17	3.97		
RX23	23.87		12.63	6.69	9.27
BX23		10			2.49
X24	112.43	102.01	102.24	108.51	114.13
RX24		7.26		17.19	14.6
BX24			15		
X25	1.25		21.42	19.46	14.25
RX25		12.78			
BX25	10			3.18	
X33		5.78			
RX33	5.18				
BX33	3.95	1.04	5.38	5.03	4.62
X34			10.16	7.32	2.11
RX34		3.66		3.4	3.21
BX34	6.05		9.62	18.62	18.54
X35	123.88	120.39	117.46	120.65	126.27
RX35	18.7	16.38	12.63		
BX35		8.96			
Y11	80	60	60	60	60
Y21	80	80	72.63	80	80
Y31	80	80	72.63	80	80
Y12	150	150	150	150	150
Y22	173.87	150.05	150	153.87	153.87
Y32	173.87	150.05	150	153.87	153.87
Y13	203.87	220.05	227.63	223.87	223.87
Y23	203.87	220.05	227.63	223.87	223.87
Y33	227.75	240.09	240.27	227.28	227.08
B1	10	10		3.18	2.49
B2	10	10	15	3.18	2.49
B3	10	10	15	23.65	23.15

7. Conclusions

Forest resource management planning has inherently multiple objectives of uncertainty and the information is also imprecise. Fuzzy goal programming may offer an alternative framework for modeling uncertainty and imprecision.

The result of this research suggests that the fuzzy HSJ technique may potentially be used in forest resource management planning to generate regulation alternatives that are good and different.

Some observations can be regarded to the fuzzy approach to planning and decision making. The classical view of optimizing the attainment of a given objective is replaced with a more practical concept. In terms of objective functions and constraints, flexibility is reflected in treating the right-hand side as flexible levels rather than absolute values.

The successfulness of this research depends on the appropriate determination of the membership function. However, this requires further investigation. Another important concern in forest resource management planning is how to generate explicit trade-off information and search for the best compromise solution. This area deserves special attention.

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S4.02-00 / S4.12-00 'Forest Resource Inventory and Monitoring / Remote sensing technology'

Special Uses of Inventory and Remote Sensing Data

Moderator: B. Koch, Germany

MODELLING INTERACTIONS BETWEEN TREES BY MEANS OF FIELD OBSERVATIONS

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Abstract

The Gibbs model and the pseudo-likelihood estimation method are applied to study interactions between trees of pine and spruce forests in southern half of Finland. The coordinates of trees have been measured on small sample plots in the original data. Only some trees from the plots are needed in parameter estimation through field measurements.

Key words: Spatial pattern of trees, Gibbs model, pairwise interaction, field observations, pseudo-likelihood method

1. Introduction

The relative spatial distribution of trees has an important role in many fields of forestry. Examples of purposes where it can be utilized are planning of forest inventory design, construction of growth models of trees or stands and problems related to forest regeneration and thinning methods. It is of importance when studying spreading of diseases or in producing of high-quality timber. In order to simulate artificial forests for different research purposes, knowledge of spatial pattern of trees is also needed.

A suitable mathematical model for locations of trees is the spatial point process model. The simplest model is the homogeneous Poisson process, where complete spatial randomness is assumed. More complicated models and mathematical tools for parameter estimation are needed if the Poisson hypothesis is rejected. Interactions between trees are modelled here by using a homogeneous

Gibbs point process. In this family of point processes interactions are taken into account and described by a potential function. We concentrate on pairwise interaction models, where a pair potential function describes interactions.

In order to find out the level and strength of interaction, a pair potential function is parametrized and the parameters are estimated applying some estimation method. Non-parametric methods can also be applied. Most of the methods suggested in the literature are based on mapped data. In practical forestry or forest research, however, it may be difficult or too expensive to have data in this form. It is more convenient to collect data in a form of what is called field observations: measurements are carried out in arbitrarily chosen trees or randomly chosen sample points on the field. Tomppo (1986) suggested the application of the Takacs-Fiksel method and Särkkä (1994) the application of the pseudo-likelihood method in estimating a pair potential function for data collected through field observations. The model and the estimation methods are briefly recalled in Section 2.

Interactions between the trees in pine and spruce forests in the southern half of Finland are modelled in this paper. In Section 3 we present the original INKA sample plot data measured by the Finnish Forest Research Institute and results of the interaction study are in Section 4. The coordinates of the trees on the sample plots are known instead of the entire maps of forest stands. Only one tree from each chosen sample plot is considered here in order to demonstrate the parameter estimation from field measurements. The parameters are estimated through the pseudo-likelihood method.

2. *Preliminaries*

2.1. Gibbs pairwise interaction model

The Gibbs point process model is a natural tool to describe interactions between trees. For each point configuration φ, the distribution $f(\varphi)$ measures how much more likely the configuration φ is for that process than for a Poisson process (Stoyan et al. 1987, p. 156-159). This comparison of configurations of interaction processes with those of the Poisson forest is natural because the trees of a Poisson process do not interact.

We concentrate on pairwise interaction processes Φ in R^2 where a pair potential function $:[0,\infty)\to R$ is applied to describe interactions between the trees. A so-called local energy is related to the probability to add a point x to the configuration symbol φ and is given by

$$\mathrm{E}(x,\varphi) = \alpha + \sum_{y\in\varphi} \phi(\|x-y\|),$$

where symbol α is a constant chemical activity connected to the intensity of the process and is the distance between x and y. We consider stationary and isotropic processes, where the pair potential function depends only on the distance between the points.

The sign and shape of the pair potential function indicate a possible inhibition or attraction between trees and its strength (see Figure 1). Roughly speaking, positive values indicate inhibition and negative ones attraction. There is no interaction at distance r with ϕ (r)=0. A well-known fact is that the Gibbs process is not usually the best model for highly clustered patterns; e.g. under hard-core condition parameters can always be estimated but testing is difficult (see e.g. Gates & Westcott 1986; Møller 1994).

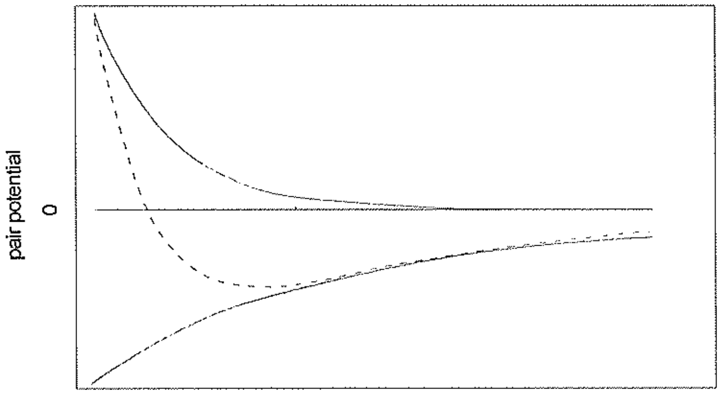

Figure 1. Examples of pair potential functions.

In the case of a bounded observation window $W \in R^2$, the density function of the pairwise interaction process is

$$f(\varphi w) = \frac{1}{Z}\exp(-U(\varphi w)),$$

where $\varphi w = (x_1, x_2, \ldots, x_n)$consists of the locations of n points in W, Z is a scaling factor, and

$$U(\varphi w) = n\alpha + \sum_{i<j} \phi(\|x_i - x_j\|)$$

the energy needed for the configuration φw (Ripley 1988).

In the present study, a special case of the pairwise interaction process, the multiscale pairwise interaction process, is applied (Penttinen 1984). Let $0 \le R_0 < R_1 < \ldots < R_m$, $m \ge 1$, be fixed real numbers. R_0 is the fixed hard-core radius (minimum possible intertree distance) and $R_m = R$ the fixed interaction radius (distance after which the trees do not interact). The pair potential function is given as

$$\phi(r) = \begin{cases} \infty & \text{as } 0 \le r \le R_0 \\ a_i & \text{as } R_{i-1} < r \le R_i, \quad i = 1,\ldots,m \\ 0 & \text{as } r > R_m \end{cases} \quad (1)$$

where $a_1,\ldots,a_m$ are the parameters to be estimated.

In order to avoid confusion with points of the process and points of R^2, we refer throughout this paper to *trees* of the process or of the pattern and to *points* of R^2.

2.2. *Estimation through field observations*

The pair potential function is parametrized and the parameters are estimated by means of some estimation method. Statistical methods developed for mapped data may be of limited use in practical forestry. Measurement of local information through sampling is often more practicable or even the only possibility. The classical field observation methods can be divided into two groups: areal counts and distance measurements. The sample units are usually sparsely located in order to get approximative independence needed in statistical reasoning. Only the Tacaks-Fiksel (TF) method (Tomppo 1986) and the pseudo-likelihood (PL) one (Särkkä 1994) have been shown to be applicable in pair potential estimation through nonmapped field observations.
The TF estimation method is based on the equality of two expectations, i.e.

$$\lambda E_0[u(\Phi)] = E[u(\Phi)\exp(-E(0,\Phi))], \quad (2)$$

where λ is the intensity of the process, u a non-negative measurable test function and E the local energy (Fiksel 1984). E_0 is an expectation with respect to a conditional distribution given a tree at a given point and E an expectation with respect to the distribution of the process. For example, if $u(\varphi)$ is the number of trees in a certain distance, then $E_0[u(\Phi)]$ is the expected number of trees calculated from an arbitrary tree, the tree itself excluded, and $E[u(\Phi)$ the expected number calculated from an arbitrary point on the study area. For the Poisson process these two expectations are equal but for general Gibbs processes weighting is needed.

The idea is to estimate both sides of equation (2) and use the method of least squares in order to minimize the squared difference. The expectations can be estimated by corresponding sample means calculated from measurements connected to chosen trees and points. Mapped data are not needed if the pair potential and test functions are chosen in a suitable way (Tomppo 1986). Measurements that are needed depend on the pair potential and the test functions (Särkkä 1994).

The PL method was first developed for Markov random fields (Besag 1974) and later for special type of Gibbs point processes (Besag 1978). The idea is to construct a PL function and maximize it with respect to the parameters. The PL function for Gibbs point processes can be derived from the one for the cell processes. The study area is divided into a grid of n_c square cells of area D such that there is at most one tree in each cell. The PL function for the system of random variables n=(n_1, n_2,...,n_{nc}) is

$$PL(n;\theta) = \prod_i P(n_i \mid \text{other } n_j, j \neq i),$$

where n_i is the number of trees in the ith cell. Therefore the PL function is a product of conditional probabilities to have one or no trees in one cell giving the number of trees in other cells. Under rather general assumptions, e.g. a hard-core distance exists, as Δ tends to zero the process converges to a point process (Besag et al. 1982). In the case of Gibbs process, maximization of the logarithm of the PL function leads to the maximization of

$$\log PL(\theta;\varphi w) = -\sum_{x \in \varphi w} E(x,\varphi \setminus \{x\}) - \int_W \exp(-E(\varepsilon,\varphi))d\varepsilon$$

with respect to the parameter θ.

The PL estimation equations coincide with the equation (2) if the test function u is chosen as a derivative of the pair potential function with respect to the parameters (Särkkä 1989; Grabarnik and Särkkä 1992; Diggle et al. 1994). Therefore, the PL estimation equations for unmapped data are discrete versions of (2) and can be derived on the basis of it (Särkkä 1994). The chosen pair potential function determines the measurements that are needed.

3. *Data: INKA growth sample plots*

The empirical data consist of the permanent INKA sample plots establishded by the Finnish Forest Research Institute for growth study purposes. The plots are distributed all over Finland. Only plots located in the southern half of the country are considered in this study (see Figure 2).

Forests can be divided into homogeneous stands according to tree and stand characteristics, such as tree species composition, age and size of trees, site fertility, etc. The size of stand vary between 0.2 and 5 hectares, typically between 1 and 3 hectares. Some type of stands have first been chosen for the study and then a cluster of three permanent sample plots are placed on each study stand. The sizes of the plots depend on the number of trees per hectare. Several characteristics have been measured describing both the forest stands and the trees on the sample plots. Examples of stand variables are dominant tree species, mean characteristics of trees, soil type and site fertility of soil. From each tree of the plots, coordinates, species, diameter and many other variables of importance in practical forestry, are measured.

The INKA growth sample plots are a special case of field observation: small regions of the study area are investigated carefully but the entire map of the whole area is unknown.

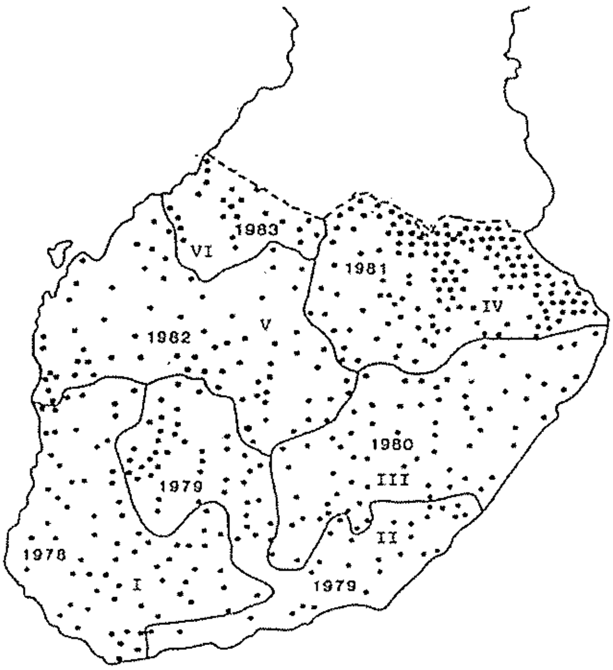

Figure 2. ***The inventory districts on INKA plots and the locations of INKA stands in the southern half of Finland.***

4. Results

The pairwise interaction process approach and INKA sample plots are applied in the study of interactions among the trees in pine and spruce forests in the southern half of Finland.

A multiscale step function model (1) with nine steps at even intervals is applied. The minimum intertree distance is used as a hard-core radius R_0. The length of interaction radius R is fixed as 3.5 m (Tomppo 1986). The model is appropriate both in inhibitive and attractive cases because $a_1,\ldots,a_m$ can have both positive and negative values. The parameters are estimated through the PL method. The estimates of the pair potentials are given but goodness of fit of the models is not tested. It can be done by using Ripley's *L* function (Ripley 1981).

The plots in pine and spruce dominated stands have been divided into three groups according to the mean diameter of the trees on the plot: 1) 0-10cm, 2) 10-20cm and 3) more than 20cm. The mean diameter of trees and the age of stands are highly correlated and therefore this grouping allows to study the spatial pattern of trees in forests of different ages. In each group, the pattern formed by the dominant and subdominant trees are studied, the suppressed ones are not taken into account.

Furthermore some arbitrarily chosen trees and sample points are needed. Tomppo (1986) suggested that the minimum adequate sample size is from 60 to 100. Sample points and trees are collected as follows: from each sample plot of interest one arbitrary point and one arbitrary tree are chosen, both of them far enough from the boundary in order to avoid edge effects. Notice that all trees on the sample plots are known here and therefore the choice of arbitrary trees is straightforward.

4.1. Pine forests

The estimated pair potential curves and the corresponding simulated forests show the spatial pattern of pine forests of different age. Young pine forests (class 1) have been regenerated by planting and are therefore regular (Figures 3a and 3b). The trees inhibit each other up to about one meter. After that, interaction becomes negligible. Naturally originated trees will appear when stand gets older (class 2) causing attraction in small distances as can be seen from the Figures 3c and 3d. Some of the trees have died or have been removed in old pine forests (class 3). The pattern of trees is regular again (Figures 3e and 3f). Pine needs much light which fact also favors a regular pattern.

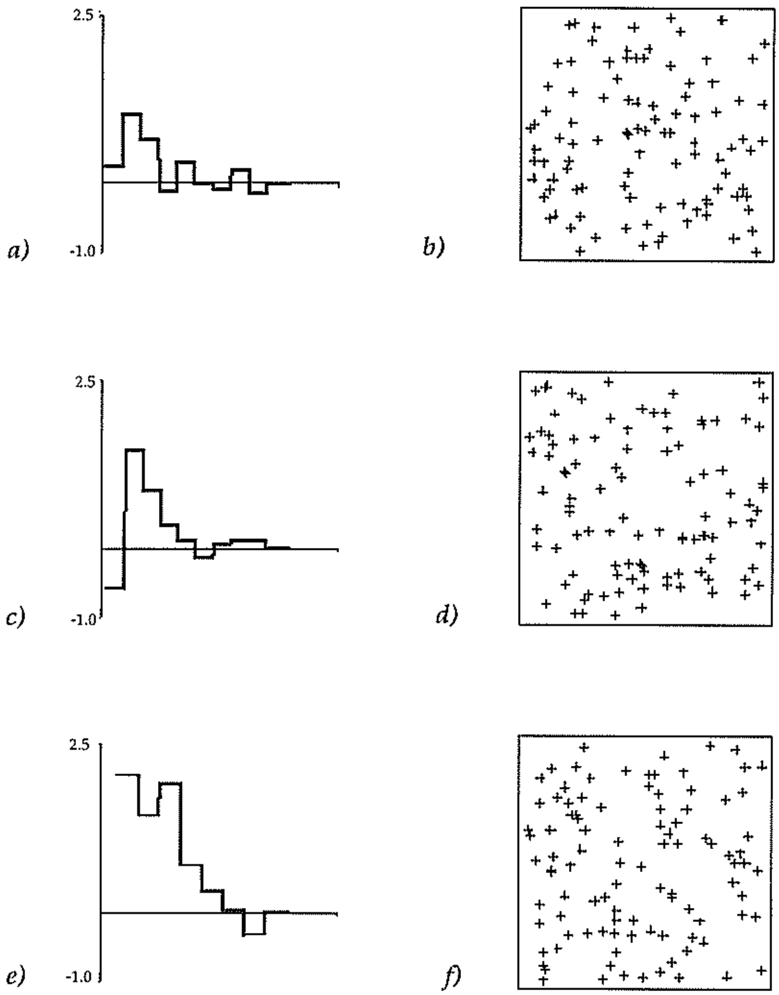

Figure 3. ***Estimated pair potential function and simulated pattern of pine forests in three diameter classes a) and b) 0 - 10 cm, c) and d) 10 - 20 cm, e) and f) over 20 cm.***

4.2. Spruce forests

Trees in young spruce forests (classes 1 and 2) attract each other in small distances (Figures 4a and 4c). Trees form small clusters as can be seen in simulated patterns in Figures 4b and 4d. Spruce does not require as much light as pine and is therefore capable of growing in small clusters. In old forests (class 3) trees form a regular pattern, probably caused by thinning (Figures 4e and 4f).

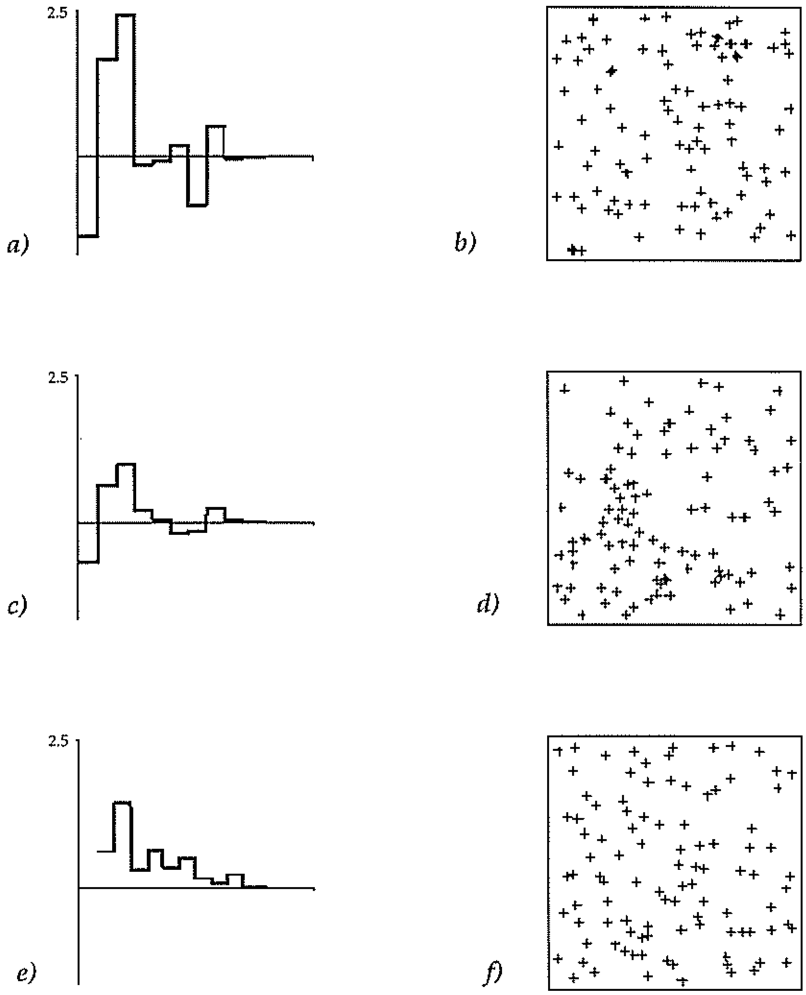

Figure 4. *Estimated pair potential function and simulated pattern of spruce forests in three diameter classes a) and b) 0 - 10 cm, c) and d) 10 - 20 cm, e) and f) over 20 cm.*

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AN EXPERT SYSTEM FOR FOREST RESOURCE INVENTORY AND MONITORING IN THE FRAME OF MULTI-SOURCE DATA

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Abstract

The study deals with the development of an expert system for improving forest inventory and monitoring by combining multi-temporal and multi-source data. The expert system is integrated with two phase sampling for stratification. The material consists of sample plot field data, TM images, aerial photographs, digital terrain models, digital soil maps and growth models. Especially multi-temporal images and permanent field plot data are combined for stratification and estimation. Three stratification methods are used. More than forty estimation procedures are compared.

The multi-source data layers and the relationships between them are represented with object-oriented programming. Multi-source knowledge is incorporated into the knowledge base with the three paradigms of rule-based, object-oriented, and procedural programming. The strategies for improving forest estimation are developed. Especially, spatial information and contextual approach are incorporated into the expert system. A belief weight function is implemented for optimizing the final estimates.

The expert system is linked with the forest inventory and monitoring system, SMI, developed in the department. The results with the expert system have shown significantly better estimates than those without the expert system.

Key words: Expert system, object-oriented programming, multi-source data, two phase sampling, unsupervised stratification

Introduction

Present forest inventory methods can be divided into compartmentwise inventories and sample plot based inventories. According to Lund (1992b), sampling methods can be divided into i) Sampling without stratification - systematic samples dominantly and ii) Sampling with stratification - especially two phase sampling for stratification.

Two phase sampling for stratification has been studied and applied in the forest inventories and monitoring in Finland by Poso and Kujala (1971, 1979), Poso (1973), Poso et al. (1984), Peng (1987), Poso et al. (1987), Jaakkola et al. (1988), Poso et al. (1990), Waite (1990, 1993). The studies have led to a microcomputer-based forest inventory and monitoring system, SMI. A sub-system for digital map data, TOPOS, has been also created. The connection with other GIS and image processing systems has been available. Experiments with SMI in Finland and Chile have suggested that the system is flexible. The methodology, however, calls for improvement, especially for combining multi-source data.

A solution to combine multi-source auxiliary data may be the use of expert systems by integrating disparate data types (Lee et al. 1987, Poso 1990). A good example was given by Skidmore (1989) when classifying Eucalyptus forest types using TM data and digital terrain models. The classification rules were derived from the knowledge of local forest service personnel and the relationships between forest type classes and terrain features (i.e., gradient, aspect, topographic position). The output of the expert system had a higher accuracy than those obtained by statistical methods including maximum likelihood, Euclidean distance classifier, etc..

This study continues the development of the SMI system. The overall objective is to improve sample based forest inventory and monitoring when multi-temporal and multi-source data are available. An expert system for this purpose is developed and integrated with SMI. The estimation procedures for combining different methods and data are defined and compared, and the best procedures for different variables are found. Especially, the results derived using the expert system are compared to those obtained using two phase sampling for stratification. All the studies have been completed as Wang's Ph.D. dissertation. This paper will summarize the studies.

Material

The study area is located in Hyytiälä, Finland. The material consisted of field plot measurements, Landsat TM satellite images, color infrared aerial photographs, digital terrain models, digital soil maps and growth models. The field data included the measurements of 196 temporary plots in 1984, and 146 permanent plots in 1986, 1989 and 1992 as second phase samples, and 1373 and 1007 temporary plots in 1984 and 1989 respectively as test samples. The four Landsat TM images were acquired in 1984, 1985, 1989 and 1992. The color infrared aerial photograph applied was taken in 1989. Three geographic variables (elevation, slope and aspect) were derived from the digital terrain model. The soil types of the first phase plots were obtained by digitizing the soil map. Two volume growth models for pine and spruce were employed.

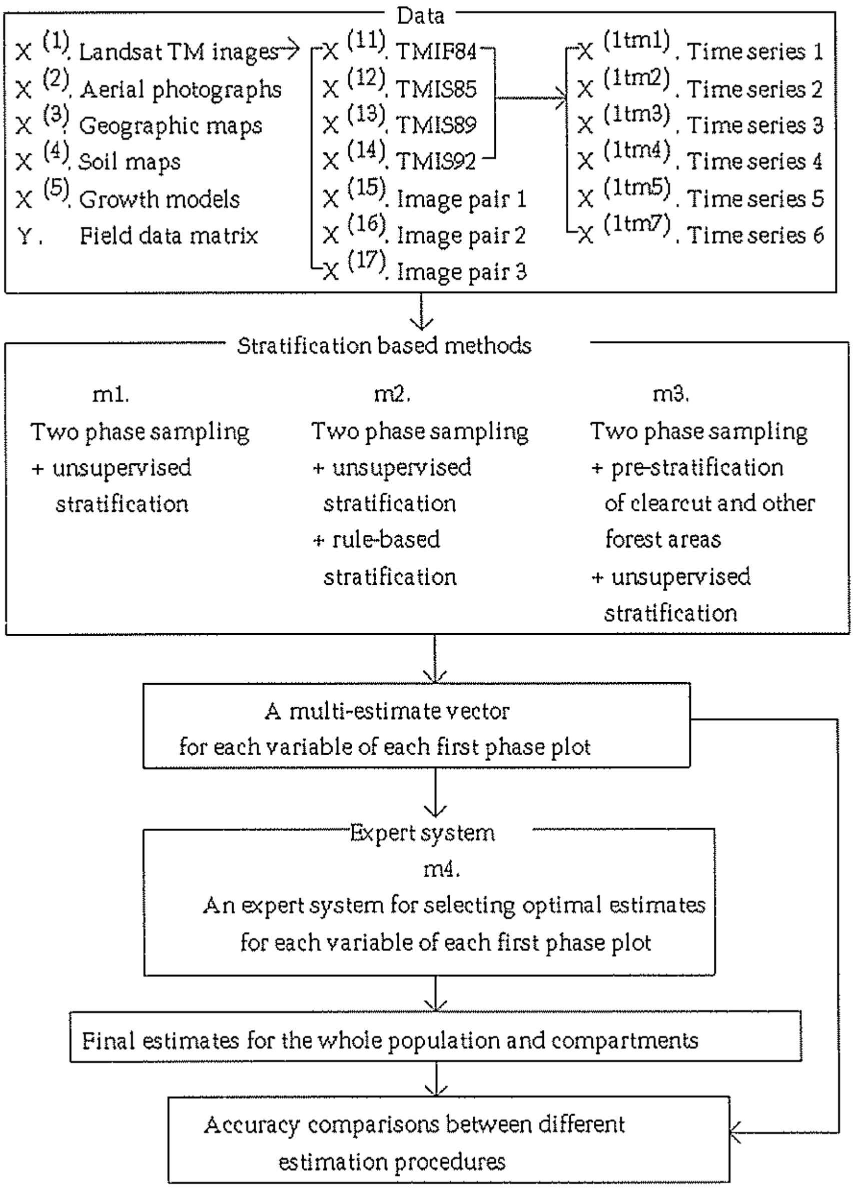

Figure 1. Study framework.

Methodology

Two phase sampling for stratification was selected as the basic estimation method. An expert system was developed to improve the estimation of the stand characteristcs. The methodology is illustrated in Fig. 1. Four Landsat TM images and three image pairs or six spectral time series were individually used as the sets of first phase data for stratifying the first phase plots without the expert system. Other auxiliary data were applied to improve the estimation of each variable by the expert system.

Unsupervised stratification was used as the basic stratification method for estimating all variables. By modifying it, two other methods: (i) unsupervised + rule-based stratification and (ii) pre-stratification of clearcut and other forest areas + unsupervised stratification, were applied for comparison.

Each set of first phase data $X^{(k)}$ led to one estimate vector $\hat{y}_{i.}^{(k)}$ for each plot. The application of L sets of first phase data produced L estimate vectors. Thus, each estimated variable j had a multi-estimate vector $\hat{y}'_{ij.}$ with L alternative estimates for plot i. The multi-estimate vector $\hat{y}'_{ij.}$ for plot i and field variable j was input into the expert system. By using knowledge and strategies, the expert system selected an expected best estimate for each variable and each plot from the corresponding multi-estimate vector. The best estimates for all field variables of plot i were individually selected from the plot's multi-estimate matrix $\hat{Y}'_i$. The above description is explained in Table 1.

Table 1. A L×q multi-estimate matrix for plot i - an illustration.

First phase data set	*Field variable*						*q-dimensional estimate vector* $\hat{y}_{i.}^{(k)}$
	y_1	y_2	y_3	y_4	...	y_q	
$X^{(1)}$	$\hat{y}_{i1}^{(1)}$	$\hat{y}_{i2}^{(1)*}$	$\hat{y}_{i3}^{(1)}$	$\hat{y}_{i4}^{(1)*}$	...	$\hat{y}_{iq}^{(1)}$	$\hat{y}_{i.}^{(1)}$
$X^{(2)}$	$\hat{y}_{i1}^{(2)}$	$\hat{y}_{i2}^{(2)}$	$\hat{y}_{i3}^{(2)}$	$\hat{y}_{i4}^{(2)}$	...	$\hat{y}_{iq}^{(2)*}$	$\hat{y}_{i.}^{(2)}$
$X^{(3)}$	$\hat{y}_{i1}^{(3)}$	$\hat{y}_{i2}^{(3)}$	$\hat{y}_{i3}^{(3)}$	$\hat{y}_{i4}^{(3)}$	...	$\hat{y}_{iq}^{(3)}$	$\hat{y}_{i.}^{(3)}$
$X^{(4)}$	$\hat{y}_{i1}^{(4)}$	$\hat{y}_{i2}^{(4)}$	$\hat{y}_{i3}^{(4)*}$	$\hat{y}_{i4}^{(4)}$	...	$\hat{y}_{iq}^{(4)}$	$\hat{y}_{i.}^{(4)}$
...	...	...	...	...	...	...	...
$X^{(L)}$	$\hat{y}_{i1}^{(L)*}$	$\hat{y}_{i2}^{(L)}$	$\hat{y}_{i3}^{(L)}$	$\hat{y}_{i4}^{(L)}$	...	$\hat{y}_{iq}^{(L)}$	$\hat{y}_{i.}^{(L)}$
L-dimensional multi-estimate vector $\hat{y}'_{ij.}$	$\hat{y}'_{i1.}$	$\hat{y}'_{i2.}$	$\hat{y}'_{i3.}$	$\hat{y}'_{i4.}$	...	$\hat{y}'_{iq.}$	

Symbol * indicates the expected optimal estimate selected by the expert system.

An estimation procedure can be defined as a special process with a special method and material to produce an individual estimate for each variable of each plot. Table 2 presents all the procedures analysed. They can be divided into: (i) stratification and (ii) expert system based procedures.

Based on the types of the estimated variables, 41 stratification based procedures were divided into four groups: (i) 12 procedures for change classification, (ii) 14 for other qualitative variables, (iii) 14 for quantitative variables and (iiii) 1 for net increments. The procedures for the same type of the variables were divided into two sets because of two different stratification methods. Each set of the procedures produced a multi-estimate vector for each plot variable. In the procedures with the same stratification method, different first phase data were applied. Thus, the procedures were compared between different methods and between different first phase data.

In Fig. 2, the expert system was designed to select the optimal estimate from the multi-estimate vector derived by the stratification based procedures. CLIPS 5.1 (NASA 1991) was chosen as the development shell of the system. Object-oriented programming (Rumbaugh et al. 1991) was used for representing multi-source data and relationships between the data layers. The three paradigms of rule-based, object-oriented and procedural programming (NASA 1991, Buchanan and Shortliffe 1984, Saarenmaa 1989) were applied for building the knowledge base. The main inference method was forward chaining based on the Rete algorithm.

Various knowledge to handle multi-source data was derived based on spatial information and the relationship between the estimated and auxiliary variables. The knowledge included:

A: statistical knowledge from the second phase sample,
B: contextual knowledge,
C: knowledge on the Landsat TM images used for stratification,
D: knowledge on growth models and
E: knowledge on other auxiliary data not used for stratification.

Based on the knowledge, the strategies for evaluating the alternative estimates were formulated. By developing a contextual approach (Gurney 1981, Skidmore 1989) and qualitative reasoning (Guerrin 1992), especially, the knowledge on spatial information was used to measure the degree of ecological association for each alternative estimate within a neighborhood of 3embed Equation.2 3 window. The similarity of the estimates of the central plot and its neighbors was the basis of measuring the degrees of ecological association. The estimate with the highest association was the most reasonable.

Table 2. *Description of procedures by combinations of different data and different methods.*

Procedures	* Definition of procedure	** Type of estimation
	Stratification based procedures	
1.1 - 1.6	$X^{(1tm1)}+Y+m1$, $X^{(1tm2)}+Y+m1$, $X^{(1tm3)}+Y+m1$, $X^{(1tm4)}+Y+m1$, $X^{(1tm5)}+Y+m1$, $X^{(1tm7)}+Y+m1$	1
2.1 - 2.6	$X^{(1tm1)}+Y+m2$, $X^{(1tm2)}+Y+m2$, $X^{(1tm3)}+Y+m2$, $X^{(1tm4)}+Y+m2$, $X^{(1tm5)}+Y+m2$, $X^{(1tm7)}+Y+m2$	1
3.1 - 3.7	$X^{(11)}+Y+m1$, $X^{(12)}+Y+m1$, $X^{(13)}+Y+m1$, $X^{(14)}+Y+m1$, $X^{(15)}+Y+m1$, $X^{(16)}+Y+m1$, $X^{(17)}+Y+m1$	2
4.1 - 4.7	$X^{(11)}+Y+m2$, $X^{(12)}+Y+m2$, $X^{(13)}+Y+m2$, $X^{(14)}+Y+m2$, $X^{(15)}+Y+m2$, $X^{(16)}+Y+m2$, $X^{(17)}+Y+m2$	2
5.1 - 5.7	$X^{(11)}+Y+m1$, $X^{(12)}+Y+m1$, $X^{(13)}+Y+m1$, $X^{(14)}+Y+m1$, $X^{(15)}+Y+m1$, $X^{(16)}+Y+m1$, $X^{(17)}+Y+m1$	3
6.1 - 6.7	$X^{(11)}+Y+m3$, $X^{(12)}+Y+m3$, $X^{(13)}+Y+m3$, $X^{(14)}+Y+m3$, $X^{(15)}+Y+m3$, $X^{(16)}+Y+m3$, $X^{(17)}+Y+m3$	3
7	$X^{(15)}+Y+m3$ or $X^{(16)}+Y+m3$ or $X^{(17)}+Y+m3$	4
	Expert system based procedures	
8	(procedures 1.1-1.6)$+X^{(1tm1)}+X^{(1tm2)}+X^{(1tm3)}+X^{(1tm4)}+X^{(1tm5)}+X^{(1tm7)}+X^{(2)}+X^{(3)}+X^{(4)}+Y+m4$	1
9	(procedures 2.1-2.6)$+X^{(1tm1)}+X^{(1tm2)}+X^{(1tm3)}+X^{(1tm4)}+X^{(1tm5)}+X^{(1tm7)}+X^{(2)}+X^{(3)}+X^{(4)}+Y+m4$	1
10	(procedures 3.1-3.7)$+X^{(11)}+X^{(12)}+X^{(13)}+X^{(14)}+X^{(15)}+X^{(16)}+X^{(17)}+X^{(2)}+X^{(3)}+X^{(4)}+Y+m4$	2
11	(procedures 4.1-4.7)$+X^{(11)}+X^{(12)}+X^{(13)}+X^{(14)}+X^{(15)}+X^{(16)}+X^{(17)}+X^{(2)}+X^{(3)}+X^{(4)}+Y+m4$	2
12	(procedures 5.1-5.7)$+X^{(11)}+X^{(12)}+X^{(13)}+X^{(14)}+X^{(15)}+X^{(16)}+X^{(17)}+X^{(2)}+X^{(3)}+X^{(4)}+X^{(5)}+Y+m4$	3
13	(procedures 6.1-6.7)$+X^{(11)}+X^{(12)}+X^{(13)}+X^{(14)}+X^{(15)}+X^{(16)}+X^{(17)}+X^{(2)}+X^{(3)}+X^{(4)}+X^{(5)}+Y+m4$	3

** Type of estimation:

1 = detecting forest change types such as clearcut, thinned plots, etc.;
2 = estimating qualitative variables such as soil class, main species, etc.;
3 = estimating quantitative variables such as age, volume, etc.;
4 = estimating the net increments and clearcut drains of quantitative variables.

* 1) The meanings of the symbols used such as $X^{(1tm1)}$, $X^{(11)}$, Y, m1, etc., are the same as in Fig. 1.
2) Without expert system, the procedures with a same method and different sets of first phase data can be compared, such as the six procedures 1.1-1.6.
3) The procedure pairs for comparison of stratification based methods without expert system:
1.1-1.6 and 2.1-2.6 for forest change type;
3.1-3.7 and 4.1-4.7 for qualitative variable;
5.1-5.7 and 6.1-6.7 for quantitative variable.
4) The procedure pairs for comparison between without and with expert system:
1.1-1.6 and 8, 2.1-2.6 and 9 for forest change type;
3.1-3.7 and 10, 4.1-4.7 and 11 for qualitative variable;
5.1-5.7 and 12, 6.1-6.7 and 13 for quantitative variable.

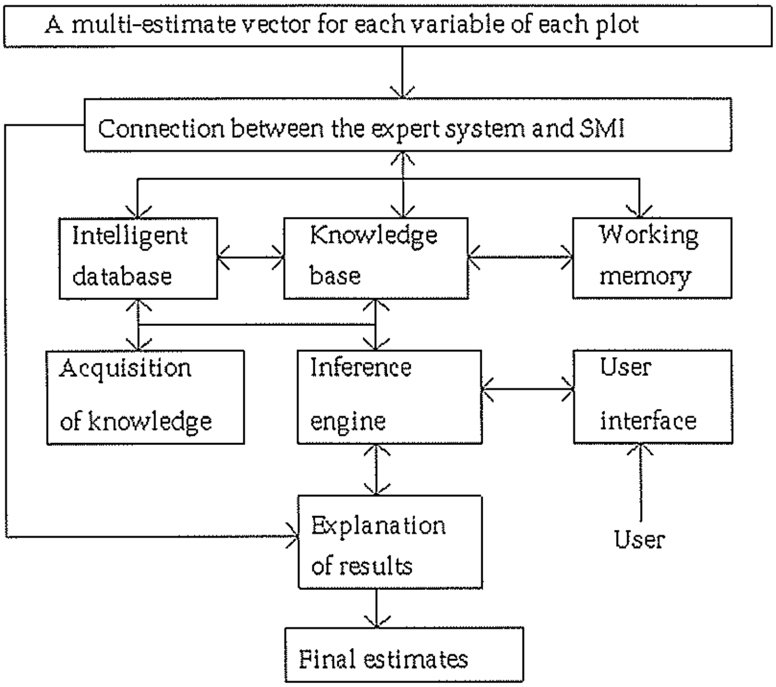

Figure 2. *Structure of the expert system.*

The alternative estimates for a plot variable were evaluated and ranked using each kind of the knowledge. A belief weight function was developed for depicting the importance of various knowledge. The final ranks were derived as follows:

$$FRC_i = \sum_{k=1}^{6} bw_k \cdot RC_{ik} \tag{1}$$

where, FRC_i = Final rank coefficient of the *i*th alternative estimate. k = Type of knowledge and k = 1 to 6 respectively indicates statistical knowledge, spatial, Landsat TM images used for stratification, growth model, aerial photograph, and the combination of geographic variables and soil type. bw_k = Belief weight for knowledge type k. RC_{ik} = Rank coefficient for the *i*th estimate by knowledge type k. The term "belief" implied that the weights were dependent on the specialists' knowledge on multi-source data and methods used. The larger FRC_i is, the more reasonable the ith estimate is.

Expert system based procedures 8 to 13 defined in Table 2 match the stratification based procedure sets 1 to 6. Each of the procedure sets 1 to 6 generated a multi-estimate vector for each field variable of a plot. These alternative estimates were evaluated and ranked with the expert system. The selected final estimates were compared to the respective alternative estimates derived using the stratification based procedures.

Results

Fourteen variables at four years 1984, 1986, 1989 and 1992 were estimated. The variables were divided into two groups: qualitative and quantitative variables. The qualitative variables consisted of forest change, soil, drainage, site, main species and development class. The quantitative variables included age, basal area, height, diameter, volume, and basal areas of pine, spruce and birch.

For quantitative variables, accuracy assessment and comparison of estimates were made with correlation coefficients and root mean square errors between the estimated and measured values. Accuracy assessment for qualitative variables was based on error matrices, percentages correct and Kappa values (Campbell 1987). Error matrix differences were tested with Kappa values and normal distribution.

1) Stratification based procedure results

For most of the qualitative variables, the best total Kappa values were over 0.280 and the highest total percentages correct were over 55%. For most of the quantitative variables, the best correlation coefficients between the plot estimates and field measurements were over 0.60. Most of the errors in percent between the mean estimates and measurements were less than 5%. Larger errors were found in clearcut, younger and older stands, and small compartments. More than 6 first phase plots in a compartment was preferable.

Two phase sampling for unsupervised stratification led to high accuracies for most estimates. Compared to the unsupervised stratification procedures 1.1-1.6 and 3.1-3.7, procedures 2.1-2.6 and 4.1-4.7 with unsupervised + rule-based stratification did not significantly increase the total accuracies of change classification and the other qualitative variables, but produced slightly better estimates for small classes. The estimation of quantitative variables was significantly improved by procedures 6.1-6.7 after adding pre-stratification of clearcut and other forest areas into unsupervised stratification procedures 5.1-5.7.

Because clearcuttings caused the largest increase of spectral values in TM5, the spectral time series of the clearcut plots clustered separately from the other change plots. The thinned and untreated plots clustered mixedly. By using spectral time series, it was possible to increase the accuracy of estimating change types, especially thinned plots. When the prior probability errors of the change types were near zero, the change classification results were optimal. The estimation procedures with TM5, TM3 and TM7 produced the best results.

When estimating the other qualitative variables, the accuracies were independent on the used image times. Image pairs did not improve the results. The best image was TMIS85, then TMIS89 and BI89+85. When estimating the quantitative variables, the better a single image matched in time with the field variables, the better the estimates. Compared to single images, the image pairs improved the estimation. The improvement of the estimates by adding pre-stratification was mainly found in clearcut and younger stands. When net increments and clearcut drains of the quantitative variables, most of the correlation coefficients between the estimated and measured values in the compartments were more than 0.70, and compared to the actual value, the error of the estimated volume of clearcut areas was -15.7%.

2) Expert system results

By using object-oriented programming and by expanding the variables to classes and slots, the field data, TM image data, aerial photograph interpretation values, digital terrain models, digital soil maps, and growth models, were successfully represented in a hierarchy of 13 different classes. The relationships between the data layers were modelled.

With the three paradigms of rule-based, object-oriented and procedural programming, a variety of knowledge on statistics, spatial information, known relationships between the estimated variables and the auxiliary variables, and the logic of estimated variables over time, were successfully incorporated into the knowledge base. The integration produced powerful strategies for ranking the multiple alternative estimates and selecting the best one for each plot variable.

Based on the knowledge, ranking rules for evaluating the alternative estimates were derived. A belief weight function was successfully developed and used to weight the different ranks. For quantitative variables, the belief weights for one kind of the knowledge were equal. Different qualitative variables received different belief weights.

Statistical and contextual knowledge were useful for all variables. Contextual knowledge had the highest belief weight and was most important. The Landsat TM images had small weight when estimating soil, drainage and site classes, and had a high weight when estimating quantitative variables, main species, development and forest change classes. Visual photo-interpretation results received the most weight when estimating the forest change types and were also important for main species and development class. Geographic and soil maps had the highest weight when estimating soil, drainage, and site classes.

The belief weights explained reasonably the importance of various knowledge and data, and it made the final estimates selected for a plot reasonable. The final rank of the alternative estimates and the best estimates were obtained by the belief function.

Six expert system based procedures were compared to six sets of stratification based procedures. The expert system significantly improved the estimates of all field variables. In change classification, the relative increases achieved by expert system based procedures 8 and 9 were over 70% and 61% in total Kappa values, and over 16% and 18% in total percentages correct. Procedure 8 was siginificantly better than procedure 9. When estimating other qualitative variables, expert system based procedures 10 and 11 gave similar accuracies and most of total Kappa values and total percentages correct were more than 0.50 and 67%. Most of the relative increases were more than 10% compared to the best stratification based procedures.

By using procedure 12 for the quantitative variables, most of the increases in the correlation coefficients between the final estimates and field measurements were more than 0.1 and the decreases in the root mean square errors over 6%. Another expert system based procedure 13 produced similar estimates.

Discussion and conclusions

The integration of two phase sampling for stratification and the expert system was successfully carried out in the frame of multi-temporal and multi-source data. The introduction of multi-source auxiliary data and various knowledge especially spatial information into the forest inventory and monitoring system was a new feature and an important improvement. Advanced object-oriented programming made it possible to incorporate multi-source data and various knowledge into the process of estimating variables by the expert system.

The strategies for evaluating and ranking the alternative estimates, especially the belief weight function for combining the results derived by various knowledge and multi-source data, were successfully formulated. At present the belief weights were derived by experts and learning from the database. The method how to obtain the most reliable weight function needs to be explored further. In addition, reasoning about uncertainty should be introduced into the system.

The final estimation accuracies of the variables and the relative increases in accuracy given by the expert system depended on the alternative estimates, the used knowledge and strategies. The better the alternative estimates were, the higher the final accuracy. The more useful the knowledge and strategies for ranking, the more the improvement. Some knowledge, especially contextual knowledge, was useful for estimating all the variables. The contextual knowledge played a very important role in selecting reasonable estimates. Some knowledge was particularly suitable for only some single or groups of variables.

The expert system can be used for estimating all kinds of variables. Thus, it is suitable for multi-parameter forest inventory and monitoring. By selecting the stratification procedures and estimation strategies, and by introducing more useful knowledge into the expert system, the system can be made more powerful. Further experimentation of the system in the field of forest inventory and monitoring will be needed.

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APPLYING FINNISH MULTISOURCE INVENTORY TECHNIQUES WITH NEW ZEALAND PREHARVEST INVENTORY DATA

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Abstract

Modern timber processing methods can shorten the time between logging and delivery of the end product to less than a week. Within a forest's long-term constraints, harvest planning can now become market driven, carried out just in time to supply the products for a sale. Information on the most appropriate trees and on the way the potential log-product yield of those trees can change in response to changing specifications and prices is of critical importance. To measure many small areas in a forest each to the required detail and precision is too expensive using ground based inventory alone.

New Zealand and Finland are far apart, with different forest conditions, but both countries have profitable forest industries which export the bulk of their production to a competitive world market. Since 1993, the Forest Research Institutes of the two have been cooperating to combine the satellite image processing techniques of the Finnish National Forest Inventory with the NZ preharvest inventory system.

Data from 188 ground plots were supplied by a forest company for a 1000 ha block of Radiata pine in New Zealand. These were combined with stand boundaries from maps and data from a Landsat TM image to predict pruned, unpruned sawlog, pulp and total standing volumes, individually for each pixel and each stand.

Jack-knifing tests indicated that estimates of plot variables were unbiased, though with high RMSE's. Stand estimates were also unbiased on average. Visual checking in the forest confirmed some of the spatial patterns of volume distribution predicted by the method. Some of the "true" estimates of stand volume obtained from ground assessment alone were based on very few plots, less than 4, and would be unreliable for harvest planning due to wide confidence intervals.

Research into the effects of stratification, and methods to segment stands into sub-areas uniform with respect to logproduct yield are continuing. The method shows promise for New Zealand plantation conditions.

Key words: Resource monitoring, satellite imagery, inventory

1. Background

New Zealand and Finland are as far apart as any two countries in the world. Their geography, climates and ecologies are quite different. The six million hectares (ha) of indigenous forests of New Zealand, - Northofagus, Podocarps and Kauri - are now mainly conserved from logging, whilst the 20 million ha of productive forest land in Finland, comprising mainly Spruce, Pine and Birch, are managed for multiple uses including timber production. New Zealand has however a rapidly expanding plantation area, currently 1.5 million ha, with new planting expected to average 50,000 ha per year over at least the next decade. The main planted tree species is an exotic, Radiata pine. Both countries intensively manage their production forests for profitable forestry, and expect to use these forests to generate economic wealth for their people. In 1994, Finland harvested 56 million m^3. and by the year 2020 New Zealand could have a sustainable yield of similar size. Both countries export the bulk of their production, and in order to do so, are driven by the needs of the international market.

Today's production forests are required to be internationally competitive, and to meet increasingly strict environmental demands in order to preserve biodiversity and sustain the productivity of the land. To achieve these requirements, information on the extent and change of the forest resource is necessary. This paper describes the cooperation begun in 1993 between the Finnish and New Zealand Forest Research Institutes to research, modify and test the multisource inventory techniques developed for Finland's National Forest Inventory for use with data collected by New Zealand's preharvest inventory system used operationally prior to harvest and market planning.

1.1 *Market driven harvest planning*

In the past, there was a lengthy delay between when a decision was made to fell a block of trees and the time of delivery of the timber, panel or paper products to the final customer. The timing of the decision was mainly production driven, derived from long-term yield regulation and management plans, modified by operational logging schedules. The sale of the end product, following sawmilling, peeling or pulping, was made with only limited ability to take the short term needs of the market into account. A merchant had to maintain large stocks, and was unable to respond quickly to changes in demand. Prices fluctuated as the market changed quickly from a buyer's to a seller's market and back.

Currently, mechanised mobile harvesting machinery, high speed processing facilities, and short timber drying or pulping schedules allow the possibility of shortening the time between deciding to harvest and receiving delivery of a specific timber end-product to less than a week. Thus logging and processing operations can be "just in time", felling trees of the appropriate quality only when required to fill a specific order for an end-product. At least in the short term, and within the constraints of longer term yield regulation, harvest planning now has the potential to become "market driven". To achieve this, it is essential that the whereabouts of those trees required to produce logs of the required type are precisely known. This knowledge must be specific to small areas of forest, cutting units, and the flexibility of the trees within each cutting unit to yield differing amounts of produce in response to changing relative values and log specifications must be known.

1.2 *Definition of the problem*

Estimates of total standing volume and volumes by log-product classes are required for each area that is uniform with respect to log-product yield per hectare, to piece size and to quality. In Scandinavia this implies the inventory must be stand based, with average stand sizes of one to five ha in area. In New Zealand, variability within the larger sized stands is such that it is desirable to be able to segment a stand into more uniform units in the order of perhaps five to ten ha or smaller in area. The total area considered during harvest planning will consist of many small cutting units, each requiring to be inventoried accurately, in detail and to a strict level of precision. Ground based inventory techniques used alone will require very high proportions of the trees to be measured, and are currently too expensive to be carried out at this intensity except on a cursory, quickly executed basis, placing great reliance on past experience, theoretical models and ocular estimates. The results from such assessments are not ideal for quantitative, computer-based planning in a rapidly changing environment.

2. *Previous work*

2.1 *New Zealand preharvest inventory*

New Zealand production forestry has been using virtually one method for preharvest inventory over the past 18 years to provide operational data to forest managers for marketing and logging planning. This is the Method of the Assessment of Recoverable Volume by Log-types, originally implemented on main frame and mini computers, Deadman and Goulding (1979), modified and upgraded as Micro-MARVL for IBM compatible PC's, Goulding et al (1993), and recently upgraded again to a windows version. This latest third version incorporates a database management system capable of integration with a GIS, Gordon et al (1995).

The inventory method has two distinct phases: the field work to collect the data, followed by computer analysis to predict the log-product volumes. In the field assessment, simple, stratified random, or double sampling and bounded or Bitterlich plots can be used. The trees sampled are measured and objectively assessed for quality or grade changes up the stem independent of the log-product specifications. The computer analysis models the breakage, volume, taper and grades of the tree stems based on the field data, and then predicts the yield of log-products by simulating the felling of the stem and mimicking the bucking into logs. Dynamic programming is used to calculate the bucking pattern for each stem such that the total value of the logs obtained is maximised. A list of log-products and their specifications, including their relative values is supplied by the user at the time of each analysis and the inventory data can be reanalysed many times with different sets of specifications.

In New Zealand forestry practice, the list of possible log- products may have six to 10 types of log-products, each with a range of lengths. The reports from the program provide per hectare summaries, dbh distributions, log-product small end diameter frequency distributions and, optionally, a tree by tree report on how and what logs were cut. The facility to vary the log-product specifications and reanalyse the data from one field assessment several times allows the harvest planner to determine the sensitivity of the yields to changes in those specifications. By projecting the inventory data forward a few years using the growth routines and reanalysing the data, the increase in volumes of various products can be accurately determined. This is particularly useful when a stand may be marginal with respect to the minimum size requirements of valuable logs. By rescheduling the date of logging to allow extra growth to occur, the minimum size may be exceeded.

The results provided from the inventory method are sufficiently accurate and useful for the amount of pre-harvest inventory in New Zealand to have greatly increased over the past decade. To estimate population totals within the confidence intervals desired by management requires 20 to 50 or more plots, involving two to six or more days work for a single field crew. Reducing the size of the area of a population does not necessarily reduce the variability, and providing estimates for smaller and smaller sized areas is limited by the amount of additional field work required.

2.2 *Finnish multisource inventory*

Finland's forest resources have been investigated by National Forest Inventories (NFI) for over 70 years. The Finnish Forest Research Institute (FFRI) has been responsible for conducting all the inventories. Line survey sampling was applied in the first (1921-24) to the fourth (1960-63) inventories. Lines ran from south-west to north-east at intervals of 26 kilometres, Ilvessalo (1927). Detached L-shaped clusters of plots (tracts) have been used instead of continuous lines since the fifth inventory (1964-70).

During the eighth inventory (1986 - 1994), the FFRI developed a multi-source inventory system which utilises satellite images and digital map data in addition to ground measurements. Rapid changes in forests in the 1980s and the importance of the role of the forest sector in the Finnish economy were the main reasons behind the further development the inventory method. New technology has made available additional sources of forest information. It has made it possible to increase the cost efficiency of an inventory and to acquire better localised information and for smaller areas than what is possible with field measurements only.

Multi-source inventory has been employed operationally since 1990. Other geographical and meteorological data will be introduced later. Results with the new system for the entire country will be ready by the end of 1995.

Field sample plots are utilised for estimating results for large areas and as ground truth data in satellite image processing. The distance between two tracts varies from south to north, due to the density and variability of the forests. In the northern part of central Finland tracts are seven kilometres apart in both north-south and east-west directions. Each tract has 15 Bitterlich sample plots, of which three are permanent and the other twelve temporary (Tomppo 1993).

Landsat TM images and, to minor extent, Spot images have been applied as remote sensing data.

Digital map data produced by the National Board of Survey are used to separate forest and non-forest land from each other and for improving the accuracy within forestry land, e.g. by stratifying the inventory area into swamps and mineral soils. A mask of agricultural areas, roads and built-up areas has been utilised in a digital form. Water areas could be obtained from base maps but they can be obtained relatively reliably from satellite images by means of thresholding. Digital elevation models are used to avoid confusion in image analysis caused by land morphology. Some administrative information such as municipal boundaries and, in the future, boundaries of forest holdings will also be used in digital form in order to differentiate computation units.

The image analysis consists of preprocessing the image (image rectification, removal of noise, striping, etc.), selection of features, classification, and postprocessing (generalisation). The method is employed so that all the inventory variables can be estimated for each pixel.

A *k nearest neighbour classification* has been applied so far. The Euclidean distance, $d_{i,p}$, is computed in the feature space from the pixel p to be classified to each pixel i whose ground truth is known (sample plots). Take $d_{(1),p},\ldots,d_{(n),p},(d_{(1),p}\leq\ldots\leq d_{(n),p})$, n~5-10 and define

$$\omega_{(i),p} = \frac{1}{d^2_{(i),p}} \Big/ \sum_{i=1}^{n} \frac{1}{d^2_{(i),p}}$$

Define the estimate $\hat{m}_p$ of the variable M for the pixel p

$$\hat{m}_p = \sum_{j=1}^{n} \omega_{(j),p} \cdot m_{(j),p} \qquad (1)$$

where $m_{(j),p}$,$j=1,\ldots,n$, are the values of the variable M in the n closest pixels in the spectral space to the pixel p, see Tomppo & Katila (1991).

The features (independent) variables are typically the original spectral values of the image bands or their functions. Ground variables can also be applied if the values are known for each pixel of the area to be analysed. Functions from the data of the digital elevation model, e.g. slope and aspect, can also be applied.

Both area and volume statistics of computation units as well as thematic maps with land use information (site fertility, timber assortments and growth by tree species, etc.) have been produced in the classification phase, see Tomppo (1993).

The spatial information of the image can be taken into account in the feature selection and/or in the postprocessing. Segmentation techniques or Gibbsian random field modelling, for example, are possible postprocessing methods, see Tomppo (1992).

3. *Opportunities for research*

Although the classification procedure was developed to be used for NFI, in Finland maps are produced and estimates made of stand parameters where the stand size is very small. The difficulty of adapting the method to New Zealand forest industry conditions lies in predicting log-product volumes with sufficient reliability and accuracy. It is very unlikely that an abundance of large branches caused by open growing conditions early in the rotation or low pruned-log volumes caused by pruning the stems to a height lower than normally prescribed, or any other feature affecting quality caused by past silvicultural practise, would affect the spectral values in the Landsat TM image. It is expected that differences in stand density and standing volumes per hectare would affect the reflectance values. Therefore, if the population could be divided into areas of similar silviculture prior to analysis, then within one such area differences in log-product yields should be related to stand density, and predicted from differences in reflectance values. Additional, reliable information is also available a priori from stand records, and this could be used by the classification procedure to supplement that provided by the six Landsat TM bands.

The questions to be answered before the system could be considered for New Zealand conditions with even-aged plantations of radiata pine are:

1) Can the classification procedure be used so that the larger population (e.g. all similar stands within a harvesting planning block) estimates are unbiased?
2) Can estimates be obtained of total standing volumes and its breakdown into log-product classes for stands and cutting units?
3) Will within-stand variation be depicted accurately?
4) What are the minimum number of ground plots required for any classification?
5) What are the confidence intervals for an estimate of a stand parameter based on the sum of the values of the individual pixels within the stand boundaries?
6) Can the procedures be used to divide a large stand into subareas which are uniform with respect to log-product yields?

4. Description of the test area and inventory data

4.1 Description of area

A Landsat TM image acquired in December 1990 was available for trialling the methodology. Part of the image covered a 1000 ha forest block within Kaingaroa state forest in the Central North Island, managed by the Forestry Corporation of New Zealand, and consisting of compartments 901 to 904, and 910 to 919. The test area comprised 29 out of the total of 45 stands within the block that at the start of the project both were scheduled for logging over the next five year harvesting plan and had some preharvest inventory plot data. Some of the other stands in the block not included in the testing had recently been clearfelled and replanted. The species was *Pinus radiata, D.Don.* planted in even aged stands. The terrain was mainly flat, though with some gullies and small hillocks in one or two of the compartments. The average site index was 28.5 m.

Stand maps at 1:10,000 and detailed records were provided by the company. Stand boundaries and silvicultural histories were therefore known beforehand reasonably well, though neither were absolutely accurate. The age of each stand was known accurately.

In December 1990 at the time the image was taken, the stands in the test area were aged between 20 and 29 years. Total standing volumes of the test stands were estimated to range from 250 to 650 m^3 / ha, with stockings of less than 200 rising to 450 stems / ha. All stands had been managed intensively with several pruning operations to a final nominal height of 5.5 to 6 m and one or more thinnings early in the rotation. The proportion of final crop trees in a stand that were high pruned varied from under 60% to nearly 100% of the total. In many of the stands a thinning with yield had been carried out after mid-rotation age. Some of these stands had this thinning carried out four years or less prior to the time the satellite image was acquired. As a significant proportion of the trees are removed in the thinning, between a half to two thirds, these stands would still be in the process of recovering to full site occupancy.

4.2 *Satellite image*

The Landsat TM image was totally cloud free over the forest. Six channels of data from bands 1 to 5 and band 7 were present, scaled as 0-255 grey intensity values. The original image had been resampled to the New Zealand Mapping Grid, with a 25 x 25 m pixel size. The complete image was clipped to a size which just included the test area. Seven ground control points with locations identifiable on the image and with accurate coordinates had been established around the area. These were used to re-rectify the clipped part of the image.

4.3 *Inventory data*

Ground truth data was provided by the Forestry Corporation from their operational preharvest inventories carried out in the block at various times between 1988 and 1991. 188 plots had been measured and analysed by the MARVL system, (Deadman and Goulding 1979). Sampling intensity has been rising in recent years; the test area had one plot every 4.5 ha, but even so half the stands would have five or fewer plots. The plots were temporary, circular in shape of 0.06 to 0.1 ha in size. Log-product yield was predicted for three broad-based classes: Pruned logs > 35 cm small end diameter (sed), unpruned sawlogs > 25 cm sed and pulpwood > 10 cm sed. The estimate for Pulpwood yield provided by MARVL was increased by assuming that 65% of the estimate of volume above the break point was salvaged as pulp. This is the Forestry Corporation inventory's standard practise. The proportions of the merchantable volume were 17%, 69% and 14%

for pruned logs, sawlogs and pulpwood respectively, on average over the test area.

Operationally, the inventory field crews are subjected to quality control of their measurements. Even so, not every plot's estimates could be thought to be completely error free, and there were some doubtful values in the data which have not been removed.

The measurements for each plot were projected to the time of the image, December 1990, using the PPM90 growth model for Radiata pine. The early attempts at using the classification methodology without doing so had results with significantly higher errors.

The locations of the plots were digitised from the appropriate stand maps. In practice, at the start of an inventory plot locations are demarcated on a map and the field crews use hip chain and compass to arrive at the correct location in the forest. It was impossible to relocate the centres of these older plots and measure their coordinates using GPS because of canopy closure. There is the likelihood that the plot coordinates were in some error, but most plots within a stand were established no more than 100 m apart, sometimes significantly less than this distance from an identifiable boundary or road, and the field crews were experienced. Errors in the location of a plot are less than might at first be supposed.

A further 37 "bare land" plots were created using the Landsat image, located in newly planted stands, cutovers, roads, skid sites and adjacent pasture. These plots were assumed to have no volume.

5. *Analysis and results*

There are a wide variety of classification strategies that can be used, varying the basic algorithm. Following some experimentation, a basic strategy was adopted of using the ground truth inventory plots with their volumes projected to the time of the image, and including the "bare land" points. Reflectance values of the six TM channels were allocated to each plot from the reflectance values of the pixel closest to the plot. The matrix of 5 x 5 pixels centred on an inventory plot is shown below for channels 3 and 4 correlated with total standing volume of the plot.

Table 1. Correlation coefficients between spectral values and total standing volume.

Channel 3					*Channel 4*				
-.26	-.27	-.20	-.15	-.16	-.24	-.32	-.29	-.27	-.23
-.27	-.28	-.22	-.17	-.11	-.31	-.40	-.37	-.29	-.21
-.28	-.33	-.29	-.16	-.09	-.41	-.46	-.42	-.30	-.22
-.24	-.33	-.26	-.16	-.07	-.35	-.38	-.35	-.22	-.17
-.18	-.16	-.14	-.12	-.07	-.26	-.22	-.23	-.18	-.22

The lower correlation values of the fifth column of pixels is noteworthy, suggesting that the image and plot locations are perhaps not entirely coincident. However, the centre pixel was correlated with volume almost as well as any other.

Table 2 below shows the basic statistics of the ground truth plot data and their associated reflectance values for the TM channels. The range in the reflectance values is very low, the largest being that for channel five, a minimum of 19 up to the maximum of 60, whilst that for channel two is only from 15 to 25. There are some unusual extreme values, but these have not been removed from the analysis.

Table 2. Statistics of the ground truth plot data.

	Mean	*Minimum*	*Maximum*
Volumes m3 / ha			
Total standing	413.3	190	810
Merchantable	377.6	146	748
Pruned logs	64.9	0	160
Sawlogs	257.2	78	584
Pulpwood	55.5	16	195
Intensities (0-255)			
Channel 1	50.9	48	58
Channel 2	17.0	15	22
Channel 3	12.9	11	21
Channel 4	58.2	49	73
Channel 5	26.2	19	34
Channel 7	7.2	4	12

(One pixel with extreme values has been omitted from the table, but not from analysis)

Correlation Coefficients between Channel reflectances and Plot Volumes

Channel	*Total*	*Merchan-table*	*Pruned*	*Sawlog*	*Pulp*
1	-0.204	-0.173	-0.112	-0.251	0.193
2	-0.224	-0.205	-0.231	-0.256	0.261
3	-0.316	-0.282	-0.331	-0.314	0.276
4	-0.421	-0.402	-0.267	-0.411	-0.018
5	-0.320	-0.289	-0.220	-0.323	0.108
7	-0.223	-0.185	-0.202	-0.214	0.180

For each pixel in stands within the test block of forest, the classification algorithm was used to predict the five volume per hectare parameters of interest: total standing, total merchantable (recoverable), pruned logs, sawlogs and pulpwood, as well as other stand parameters of Basal Area, numbers of stems, average Dbh and Top height. Five nearest neighbours were used in formula 1 above. As the number of nearest neighbours decreased below five, there was a sharp loss in the precision of the estimate, whilst more than five showed little loss in precision but an increase in the computation time required for the analysis, as illustrated in the basic classification strategy for merchantable volume, table 3. Too high number of the nearest neighbours also reduce natural spatial variation of estimation, i.e. smooths the output.

Table 3. Root Mean Square Error (RMSE).

	Number of nearest neighbours									
	1	2	3	4	5	6	7	8	9	10
Merchantable Volume	160	138	128	122	120	120	120	119	119	118
	.3	.0	.3	.8	.4	.9	.2	.5	.4	.4

A jackknifing procedure was used to validate the classification results. Predictions were made for each plot using data for the classification from only the other plots. Table 4 shows the mean predicted value, the Root Mean Square Error RMSE and average bias of the jack-knifing procedure applied to the basic classification strategy described above. Although the bias is significantly different from zero, it is less than one or two percent. In practical terms, given the other errors of the ground inventory system, the bias is low. The RMSE's are high.

Table 4. Errors in the basic classification (188 plots, 5 nearest neighbours).

Volume/ha	*Mean*	*RMSE*	*Bias*	*SD of Bias*
Total	410.3	119.5	-3.0	8.7
Merchantable	372.9	120.4	-4.7	8.8
Pruned	66.2	46.5	1.3	3.4
Sawlog	253.5	87.9	-3.6	6.4
Pulp	53.2	32.7	-2.4	2.4

Estimates of the stand parameters were calculated for each stand with ground truth plots by averaging the estimates for each pixel within a stand, and by averaging the ground truth plots. The latter estimates were assumed to be the "true" estimates, but it should be noted that these estimates were sometimes based on very few, less than three, plots. Although on average there was no significant difference between the estimates, the classification procedure clearly over-estimated stands with lower volumes per hectare, and under-estimated those with higher volumes. Figure 1 shows the error in the prediction of total standing volume per hectare plotted against the prediction for each stand. However, it appeared that the majority of stands that were overestimated came from one part of the block, compartments 901 to 904, whilst the majority of those that were underestimated came from the other, compartments 910 to 919.

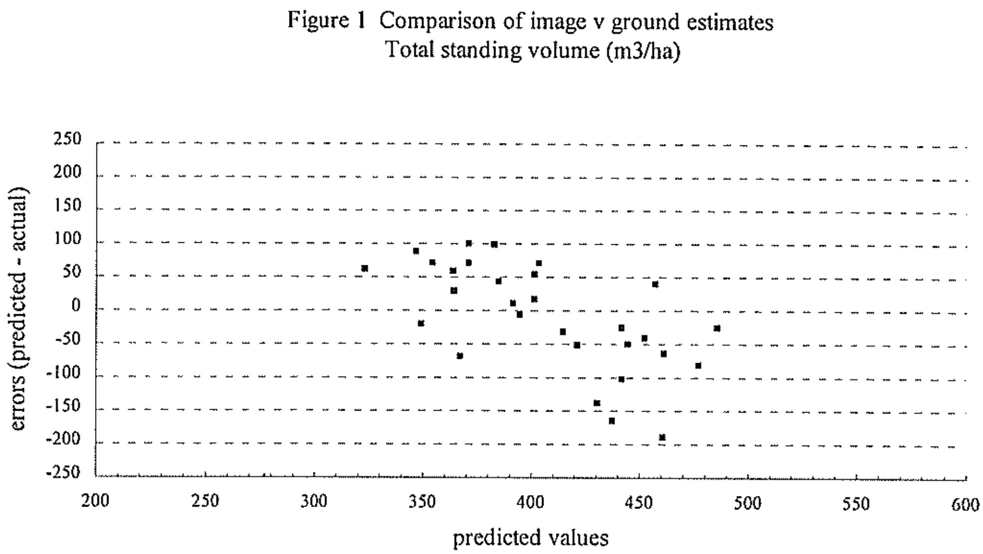

Figure 1. ***Stand level prediction errors - complete area, channels 1-6.***

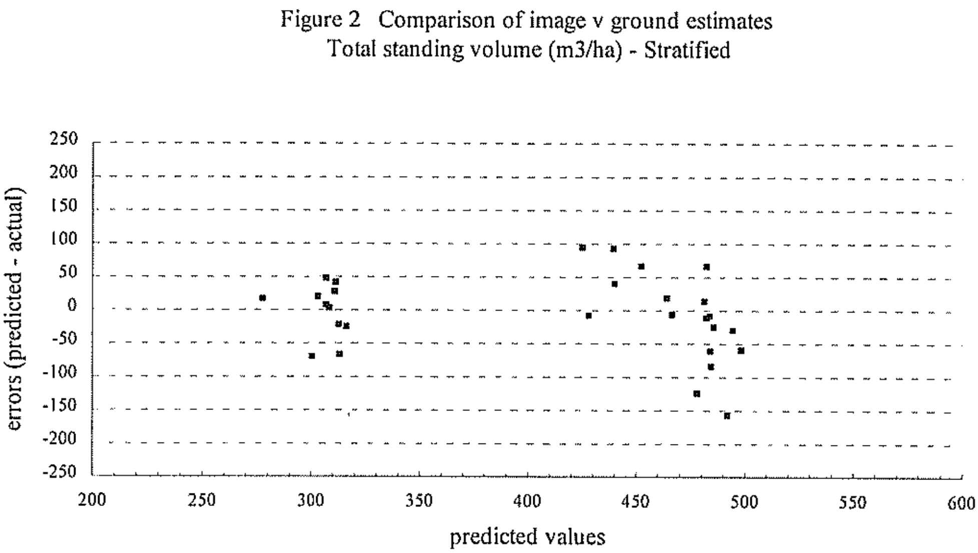

Figure 2. ***Stand level prediction errors - stratified into two strata, channels 1-6.***

These two parts differ. Most stands in compartments 901 to 904 were younger, planted between 1966 and 1970, and had been production thinned within four years prior to the time the image was acquired. The stands in the other part were planted between 1962 and 1966 and a considerably longer period of time had elapsed since the last thinning operation, at least eight years, rising to a maximum of 18 years. The stands could classified into two different strata on the basis of the ages in their stand records and their location, a priori to the analysis. Accordingly, the classification procedure was applied to each stratum separately in turn.

Figure 2 shows the errors and predictions for each plot estimated from the jackknifing procedure classified into stratum 0 (Compartments 901 to 904, younger) and stratum 1 (the remainder, older).

The bias was reduced in stratum 0 and eliminated in stratum 1. However, the stand estimates for each stratum have "separated", with a gap of 90 m3 / ha standing volume between the highest and lowest values in strata 0 and 1 respectively. This separation between the stands in the two blocks is not apparent from the inventory data. It is caused by the nearest neighbour classification algorithm underestimating the volumes of those stands in stratum 0 with higher volumes, and over estimating those stands in stratum 1 with lower volumes.

The errors in the predictions at the stand level are unacceptable, and merely dividing the block into two strata based on age/years since thinning/geographical location did not provide a satisfactory solution in itself. There is a minimum number of ground truth inventory plots that must be available for the classification procedure to work effectively, and particularly in stratum 0, the number available apparently is insufficient.

The age of each stand is known precisely. The years since the last thinning operation is also known from stand records, but with some possibility of error, particularly in those stands thinned a long time ago. As the age of the last thinning varies, and the stand is in a partially stocked condition for some time after the thinning, the number of years since the last thinning operation is likely to be a good indicator of standing volume. These two variables were added to the set of the reflectance values as input data (features) to the classification.

The question of transformations and weighting the data arises. The range of values of age and years since thinning should be comparable to the ranges of the reflectance values of the six channels. However it is also possible to weight each channel and the variables differently, on the assumption that channels with higher correlations with the volumes per hectare should carry more weight in the classification procedure.

There are a large number of combinations and not all possibilities were tried. Tables 5 and 6 show the effects on the RMSE and the bias of some of the combinations tried. Adding age alone with a weight of 1 lowered the RMSE of total standing volume from the original unstratified classification of 119.5 to 95.8. Adding years since thinning alone lowered the value to 87.5; age and years since thinning together showed no further improvement. On the assumption that differences between years immediately after a thinning should carry more weight than differences of those much further away, years since thinning was transformed by taking its square root. However this gave no improvement to the RMSE.

Weighting reflectance values by their correlation coefficient with standing volume, was poorer than using weights derived from the judgement of the researcher. In general, weighting appeared to have only a minor effect if any on lowering the RMSE.

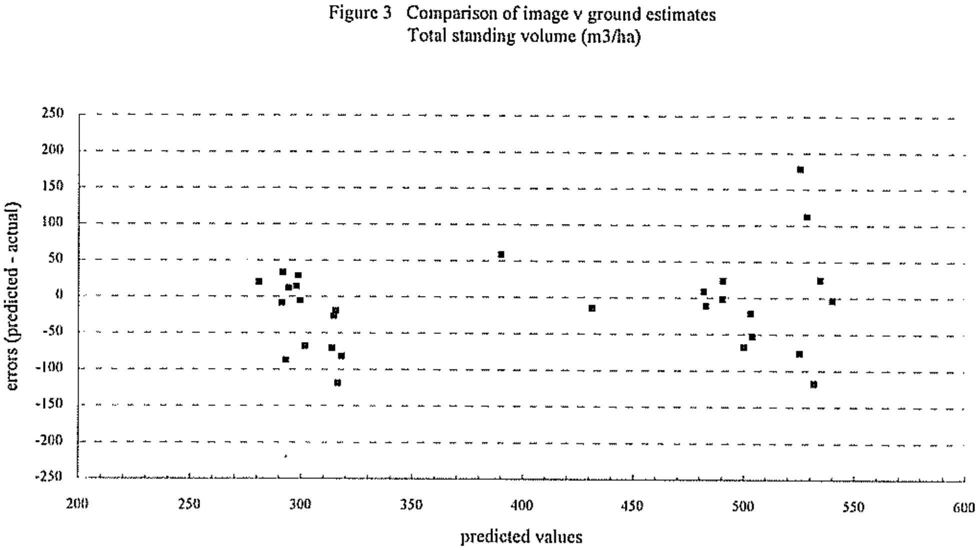

Figure 3. ***Stand level prediction errors - complete area, channels 1-6 and years since thinning.***

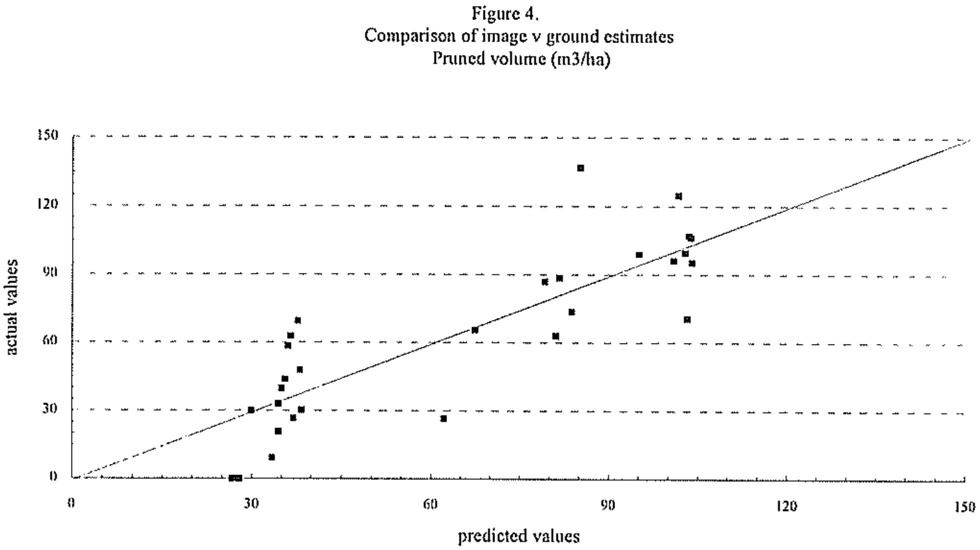

Figure 4. ***The estimation of pruned volumes - complete area, channels 1-6 and years since thinning.***

Adding the number of years since thinning, untransformed, without scaling, was the simplest and amongst the best at lowering the RMSE, by 28% for total standing volume and by 24% for pruned volume. The image of the estimated values of volume for each pixel clearly showed many stand boundaries as marked differences in volumes per hectare. However the within stand variation was less pronounced and differences more subtle than when depicted by the image from the original classification on the channels alone. The graphs of errors (actual - predicted) versus predicted for stand estimates are shown in figure 3 for total standing volume and while figure 4 shows the graph of actual against predicted for pruned volume per hectare. The correlation of bias with predicted value has been eliminated. Figure 5 shows the difference between actual and predicted plotted against predicted total standing volume by individual plots.

Visual inspection of the stands in the forest in New Zealand confirmed several observations drawn from examination of the pixel maps. For example:

- a small area of very high volumes shown on the map was unthinned and highly stocked (compt 919)
- small areas of very low volumes were found to be very small thinning skid sites, not marked on compartment maps (compt 903 and 904),
- stand boundaries between stands of different stand conditions were clearly differentiated on the pixel map, and correct when checked on the ground (compt 901 to 904),
- a single low volume pixel in the midst of an area of high volume was found to be a small area where the tops of the trees had blown out, significantly reducing the volume (compt 918).

Some areas in compartment 912 were indicated to be of high volume and with a high proportion of pruned logs. These areas were being felled first by the logging crew in the compartment, who had instructions to find high value logs, and produce them at a high rate per day.

Table 5. RMSE from Jack-knifing.

weighting / *Volumes m^3/ha*	*Unstratified*	*Stratified*	*Age (no wts)*	*Age Correlation*	*Age weighted*	*Sqrt (yrs thin) weighted*	*Yrs thin weighted*	*Yrs thin no weight*	*Age & yrs thin no weight*	*Age & Sqrt (yrs thin) weighted*
Total	119.5	103.3	95.8	96.2	93.5	88.2	88.0	87.5	87.5	87.6
Merchantable	120.4	97.3	101.0	98.8	96.8	83.2	83.3	82.9	82.8	82.4
Pruned	46.5	36.1	37.6	35.5	36.2	34.8	34.9	35.2	34.8	34.3
Sawlog	87.9	80.2	77.9	77.1	74.9	67.5	67.1	66.2	66.2	67.3
Pulp	32.7	30.9	30.6	29.6	29.6	30.0	30.1	31.0	28.3	27.0

Table 6. BIAS from Jack-knifing.

weighting / *Volumes m^3/ha*	*Unstratified*	*Stratified*	*Age (no wts)*	*Age Correlation*	*Age weighted*	*Sqrt (yrs thin) weighted*	*Yrs thin weighted*	*Yrs thin weighted*	*Age & yrs thin no weight*	*Age & Sqrt (yrs thin) weighted*
Total	-3.0	0.9	-3.7	-0.7	-4.2	-2.6	-0.5	-0.4	-1.7	-1.4
Merchantable	-4.7	1.0	-4.2	-1.7	-3.9	-1.2	0.3	0.3	-0.8	-0.3
Pruned	1.3	2.8	0.8	0.9	1.1	2.7	2.7	2.5	1.6	2.5
Sawlog	-3.7	0.5	-2.0	0.1	-1.7	-1.6	-0.9	-0.4	0.5	0.9
Pulp	-2.4	-2.3	-3.0	-2.7	-3.2	-2.4	-1.5	-1.8	-2.8	-3.8

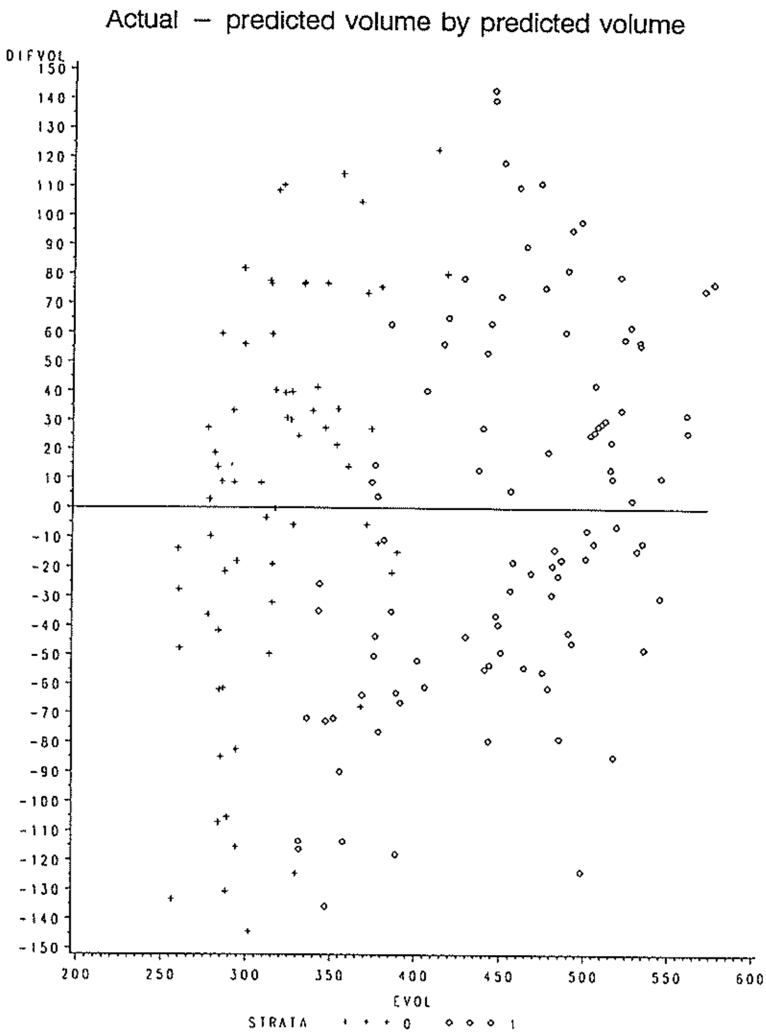

Figure 5. ***Individual plot prediction errors - complete area, channels 1-6 and years since thinning.***

6. Discussion

A moderately high RMSE of pixel predictions versus actual inventory plot values is not of itself of concern, providing it is unbiased. The level of bias shown by the jackknifing procedure across the whole population of plots, in the order of two to three % for the best classification results, is negligible in practise compared to the other errors arising in the day to day planning and management of sales, log allocation and harvesting. The RMSE of pruned volume predictions at 35% was the highest percentage of the mean of all the volume categories. This would imply confidence intervals in the order of plus or minus 70% for the estimate of volume on an individual pixel. With 16 pixels to the hectare, an area of 3 ha in size could in theory be estimated to within plus or minus 10% of the mean volume of pruned logs, provided that the assumption that the errors were purely random is correct. However there is clear evidence that the errors of predictions at the pixel level within a stand are correlated, at least in some of the classifications. This correlation will lead to bias in the stand level estimates. The amount of bias at the stand level is itself correlated with the amount that the stand means differ from the overall mean of the population of ground plots used in the classification, as shown in the original unstratified and subsequent stratified classifications. Adding additional information such as the year since thinning increases the likelihood that the nearest neighbour plots to any pixel will be those located within the same stand, thus reducing bias compared to the inventory plots, but also decreasing the within stand variation depicted by the pixel estimates.

Additional information is available from stand records which is likely to be of use when estimating pruned log volumes. Although in theory all stems remaining after the final silvicultural operation should have been pruned to the same final prescribed height, in practise some stems will have been pruned to a level lower than that prescribed in the final lift. An estimate of the proportion of the final crop stems which have received a complete treatment is often available in the stand records, having been collected in previous inventories.

Adding this extra a priori stand record information does not in itself add extra ground truth data, but improves the classification criteria. Subdividing the population into strata within which all stands are uniform with respect to silviculture and likely product yield will also have the same effect. There is a minimum number of ground truth plots which must be present within any population. They must cover the range of reflectance values and associated volumes per hectare within the population.

7. Conclusion

The level of sampling intensity commonly employed by the New Zealand forest industry in 1994 to obtain preharvest inventory information is only in the order of one plot per three to five hectares, or about a 2 to 4% sample. This is inadequate to provide the information for small areas uniform with respect to product yield in order to allow "market driven" sales and harvest planning. To obtain the required information to the necessary precision, a ten to twenty fold increase in the amount of field inventory would be necessary. The use of multi- source inventory based on remotely sensed images, good stand records and an adequate sample of ground truth preharvest inventory data holds some promise to alleviate this problem, as well as providing raster maps of the likely within stand variability of standing total and log product volumes per hectare. This project is in its early stages of work. More research is needed to improve the application of the classification algorithm, to develop segmentation techniques in order to divide a variable area into more uniform subareas, to define the minimum number of ground plots required and to explain how the confidence limits of a stand level estimate are to be calculated. Current research into the use of airborne imaging spectrometers may be applicable. A considerable amount of work is required to produce an operational system. Further in the future, the method is likely to be useful in a New Zealand national forest inventory of both the exotic plantations and the indigenous forest.

Acknowledgments

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WOODY BIOMASS MAPPING, USING FIELD DATA AND SPOT-SATELLITE IMAGERY

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Abstract

A woody biomass inventory was carried out in a forest area of Tunisia. A subsampling procedure was developed for field use to estimate woody biomass (volume, fresh and dry weight separately of stem- and branch wood) of individual trees of *Pinus halepensis*, *Eucalyptus camaldulensis* and *Eucalyptus gomphocephala*. The procedure used a hand-held Sharp PC 1600 computer, for data recording and initial processing in the field. While in the field, estimates are obtained on tree volume and fresh weight; dry weight was calculated after oven-dried wood samples. This procedure, being the most costly part of the work, proved highly cost-effective, and provided unbiased estimates.

Next, woody biomass equations were developed, using weighted linear regression techniques. It was found that there was no justification to differentiate between species. Third degree polynomial equations based on dbh resulted.

A SPOT satellite XS-scene was used for classification and stratification of the forest. Using a stratified random sampling procedure, pixels were selected. These pixels were located in the field with the help of a portable GPS receiver. Circular field plots with the same size as the pixel area were laid out, and enumerated. An application of the biomass equations to the field plot diameter data provided woody biomass for each plot.

Several image transformation techniques were applied to the SPOT scene of the area, and relationships with field plot biomass were sought. The Normalized Difference Vegetation Index gave the highest correlation ($r>0.92$) with plot-woody-biomass. This permitted the production of a woody biomass map for the area.

Key words: Biomass assessment, remote sensing, regression analysis, GPS

Introduction

The Arabic traveller and historian Iben Kaldoune (1332-1406), himself a Tunisian, in his book "El Moukadama" described North Africa as a land of continuous shade. At that time people travelled from Tripoli to Tanja under the shade of trees. Today, the forest area in Tunisia covers only about 4% of the country, and is dominated by maquis and a very small part of natural forest of Oak and Pine. Forest cover is ever decreasing giving place to desert. However, an important number of reforestation and afforestation projects are now in progress with the aim to reduce desertification and erosion problems, and to help solving the timber shortage.

In 1989, Tunisia started its first national forest inventory to get information on the state and potential of its forest resources. During the process it was found that the procedures employed for estimating the amounts of polewood, firewood, timber and charcoal, were very time consuming. This paper describes a study on cost-effectiveness of woody biomass estimation, using SPOT satellite imagery, a Global Positioning System, and a tree subsampling procedure for forest mapping in the Tebourba forest in the northeastern part of Tunisia.

The species concerned are *Pinus halepensis*, *Eucalyptus camaldulensis* and *Eucalyptus gomphocephala*. The were planted since 1954. The forest area covers some 9000 ha, of which 60% is maquis. The climate is Mediterranean, with annual precipitation around 470 mm, and a long dry summer.

Methods

A SPOT satellite XS image of 14.09.1992 was available. Image processing was done using ILWIS. Radiometric correction was applied for haze elimination. A 1:25 000 topographic map and 30 well-distributed ground control points were used for geometric correction. Ratioing was applied to remove the effect of varied illumination due to shadow effects. Next a supervised classification was carried out, using the ground knowledge of the second author, aerial photographs (B/W infra-red, scale 1:20 000, June 1989) and the topographic map. The six classes were Pine plantation, Eucalyptus plantation, Shrub land, Mixed Eucalyptus and Pine plantation, Agricultural fields, and Orchards. Bands 2 and 3 (red and near-infra-red) best facilitated the separation of the training classes. Overall accuracy was 94%. The lowest accuracy for any class was 86%.

Using the classified image, fifty pixels were randomly selected from the Pine, Eucalyptus and mixed Eucalyptus/Pine stands, distributed in proportion to their respective areas, and their coordinates recorded. In the field, the same 50 points were subsequently located using a Magellan NAV 1000 M Global Positioning

System. The openness of the forest stands proved an advantage to the receiving possibilities of the GPS. Each point formed the centre of a circular plot of 400 m^2 (equal to the SPOT pixel size).

The same points were also transferred to the aerial photographs as accurately as possible. By interpretation, the points could also be located in the field. This was done to test the accuracy of the GPS.

In each of the fifty sample plots, all trees with dbh 7 cm or larger were enumerated. Plot enumeration included trees with a minimum diameter at breast height of 7 cm. The variables recorded were: tree species, diameter at breast height, diameter at butt level, total tree height, crown diameter and crown height.

In each plot, two trees were selected for subsampling, in order to provide biomass equations. These two trees were the one nearest to the plot centre, and the tree with biggest diameter. It had been found in earlier research in The Netherlands (De Gier 1989) and in Burkina Faso (Kaboré 1991) that this would result in a near-even diameter distribution of the trees to be subsampled. A total of 100 trees was thus selected. Subsampling was done on the basis of the method described by Valentine et al. (1984), which was adapted by De Gier (1989) for woody biomass estimation in woodlands.

This method combines randomized branch sampling, through which a path through the tree is determined. The path starts at the butt and terminates where the minimum diameter is reached. At each branching point (which can be at the butt), a random selection is made with which branch to continue. The selection probability of branch i out of all the branches at the particular branching point is equal to ($d_i^{2.5}/\Sigma d^{2.5}$), i.e. proportional to the diameter raised to the power 2.5. In this way the probability of each segment (i.e., the part between two successive branching points) can be calculated. Selection continues, until a segment reaches the minimum diameter of 7 cm. The unconditional probability to be in any particular segment is then the product of the probabilities of the preceding segments. Having selected the path, importance sampling is applied. This starts by measuring carefully the diameters and distance to the butt at those points in the path where taper changes. This permits, by using the formula of Smalian, the calculation of the volume of the path, and, since the unconditional segment probabilities are known, the volume of the entire tree can be calculated, up to the defined minimum diameter. The path is thus considered to be a set of superimposed truncated cones. Using importance sampling, the location of a random point in the path can then be selected with probability proportional the diameter squared. At this point a disc of some 10 cm thickness is removed. Using the disc fresh weight and thickness, the unconditional probability of the segment where the disc was removed, and the tree volume and the calculated diameter squared at the point of removal, an estimate of the tree fresh weight is obtained. After oven-drying the disc, the same calculation is performed, whereby disc fresh weight is replaced by disc dry weight. This results is an estimate of the oven-dry weight of the tree. To facilitate the selection procedure and the required calculations, a program was written for a hand-held Sharp PC 1500A or 1600 computer. Tree volume and tree fresh weight can then be determined right at the foot of the selected tree. Errors can still be corrected before moving to the next tree. Discs can be brought periodically to a place with controlled wood drying facilities. If discs are large, they can be split into wedges. The program permits the random selection of one wedge. In practice a weighing scale with a capacity of 200 grams is therefore adequate for most trees.

Results

The use of the GPS proved very advantageous. Using aerial photointerpretation as a check, the GPS permitted the plot centre location, on average within of 20 meters.

For each one of 100 trees data were available on volume, fresh weight, dry weight, diameter at breast height, diameter at butt level, tree height, crown diameter and crown height.

Because of species identification problems in the field, the two Eucalyptus species were combined. Seventy-four trees were Eucalyptus; 26 were *Pinus halepensis*. For both Pinus and Eucalyptus trees, diameter at breast height was found to yield the highest correlation coefficient with tree volume (r=0.90 and 0.95), tree fresh weight (r=0.78 and 0.91), and tree dry weight (r=0.88 and 0.90). Crown diameter had the lowest correlation coefficient.

Starting with a third-degree polynomial, weighted linear regression with backward elimination was used. To obtain a homoscedastic variance of the residuals, a weight of d^3 was used. The final significant models were:

$$Y = a_1 + a_2 d + a_3 d^3$$

All three regression equations were highly significant (F-values of 90.43, 11.54 and 21.65 respectively). Interestingly, analysis showed that no difference between species was necessary. Each model applied equally well to the individual species as well as to both combined. This is in line with earlier findings in The Netherlands in Burkina Faso, where, however, a minimum diameter of branchwood of 2.5 cm was used.

Table 1. Regression coefficients

	Tree volume (m3)	*Tree fresh wt. (kg)*	*Tree dry wt. (kg)*
a1	-0.1301E-1	0.2944E-2	0.1022E-4
a2	1.0656E+1	0.2237E+0	0.8167E-2
a3	-0.1271E+0	0.6537E+0	0.4174E-2

Having established the equations for tree woody biomass, they were applied to the tree data of the 50 plots, resulting in plot biomass. This was calculated for Pine, Eucalyptus, and Pine and Eucalyptus combined.

Using the relevant band data of the SPOT image, the following vegetation indices were calculated: NDVI; Tasseled cap transformation; Perpendicular vegetation index; Leaf area index. Using an exponential regression model, correlation coefficients were calculated for each one of the vegetation indices and the plot volumes, differentiated by species. It was found that the Normalized Vegetation Index gave the highest correlation for individual species and for all species combined (Table 2).

Table 2. Correlation coefficients of biomass models based on vegetation indices and plot volume (m^3/ha)

Vegetation Index	*r*
NDVI	
Pinus halepensis	0.921
Eucalyptus spp.	0.971
Species combined	0.958
TASSELLED CAP	
Pinus halepensis	0.821
Eucalyptus spp.	0.875
Species combined	0.862
PERPENDICULAR VEG. INDEX	
Pinus halepensis	0.861
Eucalyptus spp.	0.943
Species combined	0.924
LEAF AREA INDEX	
Pinus halepensis	0.881
Eucalyptus spp.	0.848
Species combined	0.832

Variance analysis showed that all vegetation indices were highly significant. Due to the small number of field plots (50) validation was not possible.

Using the established relationship between NDVI and plot biomass, a biomass map of the forest area was produced.

Time analysis was undertaken by calculating the simulated time requirements when applying the standard Tunisian inventory procedures for the study area, and the actual time requirements of the current study. The same number of trees and plots applied in both cases.

Time requirements (in person-hours) included office work and field work. The results were as follows (Table 3).

The major difference is due to the field work. The tree subsampling method applied in the current study is particularly responsible for this. Average time per tree were a mere 34 minutes for a crew of two (Figure 1).

Table 3. Time requirements (person-hours) for two procedures.

	Standard Tunisian procedures	*Current Study procedures*
Office work	78	48
Field work	375	57
TOTAL	453 ph	105 ph

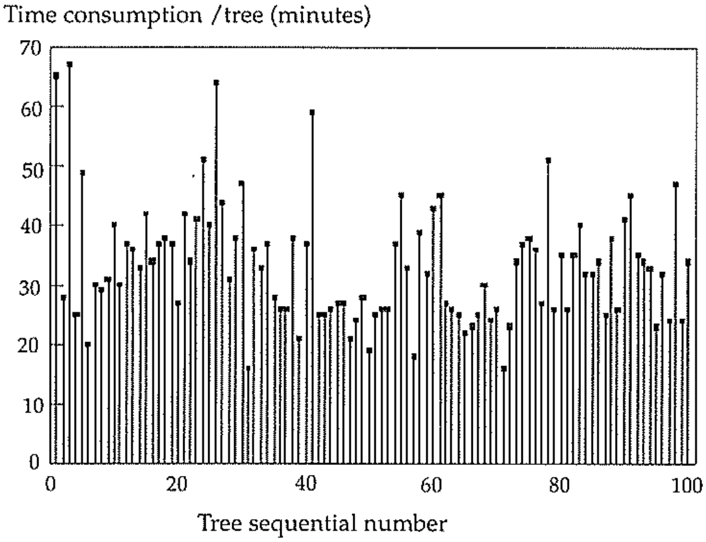

Figure 1. Time consumption per tree.

Conclusions

The current study proved to be very time efficient. For the same number of plots and trees, less than 25% of the time for the standard Tunisian procedures was required. To this should be added that the Tunisian procedure provides only volume estimates, whereas the current study also yielded fresh and dry weight estimates.

The SPOT image based Normalized Difference Vegetation Index (NDVI) gave the best correlation with plot biomass. This permitted the production of a woody biomass map of the area.

The use of a Global Positioning System was found to be very effective in locating field plot centres. The accuracy found, certainly contributed to the high correlation between the NDVI and plot biomass.

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ANTHROPOGENIC TRANSFORMATION OF FOREST COVER IN CENTRAL SIBERIA

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Abstract

A 1:2500000 map is analyzed for Central Siberian forest disturbances caused by industry, agricultural activities, felling, fires, insects, diseases, and disastrous events. Data on losses in forest productivity due to reduction in forest area and changes in age structure, density and composition of stands are presented for a number of natural zones. An original methodology is discussed of studying and mapping ecological state of forest areas based on indices of ecological potential of the environment and actual forest productivity. Obtained estimates can be used to get a better understanding of the role of Siberian forests in the global ecological cycles.

Key words: Forest disturbances, remote sensing

1. Introduction

Siberian forests are of great interest for people all around the world from the viewpoint of global ecology and development of social, economic and commercial relations. They are one of the biggest sources of organic carbon and they are the major climate controlling factor in the Northern hemisphere. Siberian forest are unbelievably rich in wood and non-wood resources. Therefore, their stability and normal functioning is vitally important for social and economic life both in Russia and many other countries.

In Siberia, forest cover has gone through a significant anthropogenic transformation for the past fifty years. This transformation has been a result of direct economic forest exploitation, influence of fire and biotic factors, and changes in the ecological conditions of vegetation growth due to technogenic pollution of the forest areas. The forests are annually cut in vast areas for industrial purposes. Forest stands are damaged or completely destroyed by fire, insects, industrial pollution, and natural disasters. Dark coniferous stands are often replaced by hard wood species in cut and burnt areas. Due to the factors above, natural forest regeneration becomes very slow under certain site conditions, thus increasing the area of non-productive forest land. Strong anthropogenic stresses lead to big and durable disbalance in the dynamics of forest ecosystem and lowers the ecosystem level of organization (completely). These processes change considerably the role of Siberian forests in ecological cycles both on a local and global scale.

Identification and quantitative estimation of current Siberian forest cover development trends require organization of permanent observations of its state, use, and regeneration. A system of spatial and temporal forest monitoring should be based on GIS technology and created through the combined use of traditional forestry information sources and new data that remote sensing methods can provide. Computer-aided digital and map data bases would allow to analyze past changes of forest cover in many regions and predict probable future trends in the dynamics of its composition, structure, productivity, and ecological functioning.

At V.N. Sukachev Institute of Forest, Siberian Branch, Russian Academy of Sciience, a computer information system for monitoring forests of Central Siberia is now being developed. The system is intended to provide local economics administration and nature protection agencies with operational information on current and expected state of forest areas for optimal decision-making at all management levels. The organization of a complex forest monitoring system is believed to promote a gradual transfer to sustainable principle of forest cover management in order to support its permanent development and biodiversity.

As regards to its purposes and input data organization, we have distinguished three levels of monitoring: regional, subregional, and local. The regional level deals with the organization of general observations covering the whole forest area of Krasnoyarsk Territory. At the subregional level, forest monitoring is conducted in areas under intense anthropogenic stress. Local monitoring focuses on the state of vegetation in separate forest management areas (FMA) and uses operational information on current forest ecosystem changes.

The first and most important step on the way to a monitoring system is related to forest inventory. This involves studying and mapping out the current state of the forest along with the identification and quantitative estimation of forest fund changes induced by both internal and external factors. In this respect, it is very important to choose appropriate quantitative and qualitative indicators of the forest state. Many researchers (Miny 1990,1992; Solbrig 1991; Brooks 1992; Teplyakov 1994, and others) believe that sound forest functioning can be judged by the following major criteria: stable biodiversity and productivity of ecosystems, their ability to self-regenerate, and the strength of their influence on ecological cycles of different scales. A system of current forest state indicators (descriptors) is now available (Miny 1992). As for monitoring, it is reasonable to use only indicators of predictive character, which can integrally reflect the state of all major ecological forest functions. The most informative current forest state indicators include per cent proportions of natural and transformed forests, forest thinning dynamics (Mikhailol 1989, Miny 1992, Sushchevsky 1992, and others), and external factor-induced forest productivity losses (Abaturov 1979, Baburin 1984, Pleshikov et al. 1991, Ryzkova 1995).

This paper addresses a number of approaches to investigation and mapping out of Central Siberian forest disturbances and analysis of current state of forest in various natural zones and FMAs on the basis of productivity rate. The study was conducted on different spatial scales and involved the use of methods of remote sensing and GIS technologies.

2. *Study area and methods*

The rate of forest cover disturbance was determined, from the ratio between natural and transformed forest areas, and mapped (1:2500000) for a part of Central Siberia (84-105 E and 54-70 N). Geographically, this area covers a part of Western and Central Siberia (within the boundaries of Krasnoyarsk Territory). We analyzed the current state of a climatic sequence of biomes including forest-steppe, southern, central and northern taiga forests, forest-tundra, and mountains of the southern part of Siberia. More detailed studies on the role of various factors in current forest dynamics and forest productivity change were conducted in sample sites established in Angara region (97°00' - 97°40'E, 57°20' - 57°50'N) and Minusinsk depression (91°30' - 93°15'E, 53°20' - 53°40'N).

Spatial forest cover patterns and succession characteristics in transformed forests are determined by ecological conditions. Therefore, forest disturbance studies were based on the landscape approach. Also, the landscape approach allows to increase the reliability of spatial and temporal extrapolation of the results obtained in sample sites.

Landscape-based division of the study area was done by using black-and-white 1:1000000 - 1:500000 images taken in the summer and winter along with spectrozonal and composite multiband images of the same scale from Cosmos satellites. The state of forest in sample sites was evaluated through the analysis of both 1:200000 summer composite images and 1:12000 - 1:15000 aerial photographs. Thematic interpretation of the remotely sensed data involved visual and instrumental methods (Kalashnikov et al. 1987). Natural units of different sizes and stages of forest degradation were identified when analyzing geometrical image parameters taking into account vegetation composition and structure judged from both direct and indirect indicators (descriptors).

The study of the current forest state required multistep data collection and consisted of three major stages - preliminary, experimental, and laboratory.

During the preliminary stage, we collected map and digital forest inventory data, reviewed archives and literature related to the study area, made landscape-based division of the area using the results of aerial survey, established sample sites, and different forest disturbance categories through the analysis of large scale imagery.

Field experiments were conducted in sample sites in order to perform ground validation of the results of preliminary aerospace data interpretation. The work performed in landscape profiles and transects allowed us to find out major forest transformation factors, identify forest regeneration stages, and understand specific features of these processes occurring under different ecological conditions.

At the laboratory stage, collected data were systematized and analyzed. A model forest disturbance map was built and provided with a legend, and current forest dynamics trends were described for a variety of natural zones and landscape complexes.

When estimating forest disturbance, we considered the state of all vegetation components - overstory, regrowth, understory, and ground cover. The level of disturbance was judged by the percent ratio of disturbed forest area to the total area of the elementary forest management unit (EFMU) under consideration. Five categories of forest disturbance were determined. A very low level of disturbance is characteristic of stands lightly affected by man, which experienced salvage cuts and low-intensity surface fires. The low, moderate, high, and extremely high levels of disturbance are observed when destructed vegetation components account for 10-30%, 31-50%, 51-70%, and 71% respectively of the total EFMU area.

Disturbance of forest ecosystems at different succession stages was estimated depending on the time needed for a native stand to regenerate from the moment a destruction factor first occurred (Krasnoshchekov et al. 1990; Titov and Mikhailov 1994). Native stands with 90-year-old overstory were assigned the category of very low disturbance, whereas those with overstory aged 70 and 40 years were categorized as little and moderately disturbed, respectively. The high level of disturbance is characteristic of stands whose native woody species is regenerated through hardwood species in 130-150 years. Stands where edificator regeneration has occurred through species replacement and has taken 200-300 years are considered extremely disturbed.

In the sample sites, forest disturbance was thoroughly estimated based on the parameters of productivity process. Productivity loss (P_W) due to factors, such as stand age structure degradation, changes in stand density and composition, and forest area decrease, is calculated using the following equation:

$$P_w = \frac{W_p - W_f}{W_p} \cdot 100$$

where W_p is the potential standing volume per hectare, which describes ecologically probable productivity across an area characterized by a given forest composition, and W_f is the actual standing volume per ha (Baburin 1984).

The potential forest productivity was calculated by dividing the volume of mature and old stands by areas they occupy. The actual productivity was determined from the ratio between the total standing volume and the total area.

Ecosystem productivity is primarily controlled by site conditions. Therefore, we classified sample sites by the type of site conditions (TSC). As for types of site conditions, we considered mesorelief, mechanical composition of soil components, the soil-ground layer stratification, and soil type. The quality of site conditions was estimated using a soil-ecological index (SEI)calculated as:

$$SEI = c_1 H \cdot f_1(H) + c_2 PC \cdot f_2(PC) + c_3 BD \cdot f_3(BD) + c_4 HC \cdot f_4(HC)$$

where c_i is weighted factor coefficient (H is humus load in the layer 0-50 cm deep, ton/ha; PC is physical clay load in the same layer, ton/ha; BD is bedrock depth of location, m; HC is humidification coefficient corrected for slope degree and aspect), and f_i is the function of the above parameters ranging from 0 to 1 (Krutko et al. 1982, Pleshikov et al. 1991).

In order to obtain a detailed characteristics of the current forest ecosystem in various natural zones, we used 1:25000 ecological maps. The latter rest on a geobotanical map, which in turn is based upon ecomorphological classification reflecting phytocoenotic and ecological characteristics of forest ecosystems (Sukachev 1964, Gribova and Isachenko 1972). Each EFMU (or elementary contour) reflected on the ecological map was characterized by a number of descriptors including average stand height at the age of 100 (potential productivity), SEI, above-ground phytomass amount (actual productivity), and an index of realization of site resources by ecosystems (K) calculated as:

$$K = \frac{P_f \cdot SEI_{max}}{SEI_f \cdot P_{max}} \cdot 100$$

where P_f is actual phytomass in a given EFMU, ton/ha; SEI_f is soil-ecological index of the EFMU; P_{max} is maximum phytomass measured in the forest type characteristic of the EFMU, ton/ha; and SEI_{max} is maximum soil-ecological index of the EFMU with maximum phytomass.

On the basis of this realization index, which shows how effectively vegetation uses available site resources, forest ecosystem disturbance maps were developed reflecting the characteristics of current forest state in respect to productivity process.

The productivity of forest stands was calculated using regression equations based on sample site inventory data. This involved a selection of appropriate indicators from a forest inventory data base with the help of software dBASE III plus.

3. *Results and discussion*

Forest is a highly dynamic natural phenomenon. Even native vegetation communities are only relatively stable. Due to continuous natural processes (climate fluctuations, changes in soil-hydrological conditions, insect outbreaks, and others), forest cover is usually represented by a wide variety of secondary phytocoenoses characteristic to different stages of native forest type regeneration.

For the past 50 years, wide-scale forest land cultivation activities in Siberia have brought about a significant transformation of natural forest development trends. Increase in annual forest fire coverage, local pollution-induced decrease in forest resistance to insects, and increasing wood extraction from year to year - all this has resulted in native ecosystem structure disturbances and contributed to forest cover modifications caused by man. This is confirmed by the analysis of a fragment of a Central Siberian forest disturbance map (Fig.1).

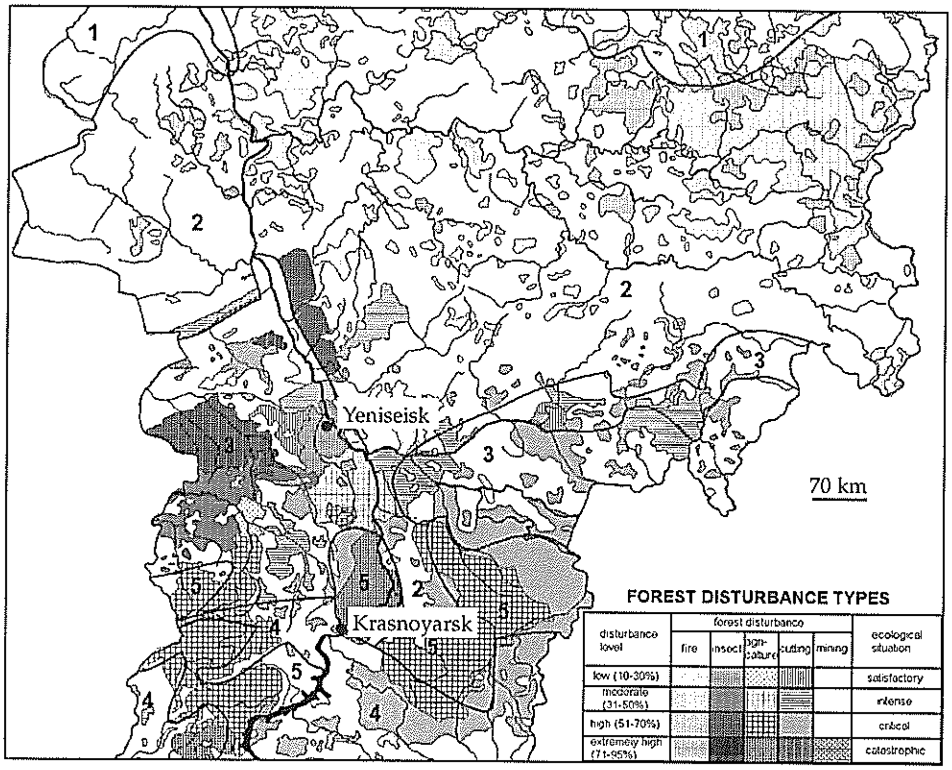

Figure 1. *Central Siberian forest disturbance map (a fragment). Subzones: 1) north taiga, 2) middle taiga, 3) south taiga, 4) Altai-Sayan mountains with steppe, taiga, grasslands and tundra, 5) zone of subtaiga, forest-steppe and steppe. — = boundary of zone, subzone.*

Economic forest exploitation began in the south and gradually advanced to the north, i.e. from the forest-steppe, subtaiga, and southern taiga forest zones to the central taiga forests. The level of forest disturbance also changes following this direction. The highest level of native forest transformation is observed in better economically developed regions of forest-steppe, and subtaiga and southern taiga forests. This is attributed to higher population density, well-developed transportation system, and the highest productivity of conifer stands under these conditions.

In the forest-steppe and subtaiga zones, disturbed forests account for up to 70-80% of the total forest area. Forests cover less than 30-35% of the total forest-steppe zone. The main factors responsible for the forest-steppe ecosystem degradation include forest land cultivation, application of herbicides, and unnecessary and unsystematic cuts. The area of wood extraction for industrial purposes accounts for 80% of the subtaiga forest zone.

Among anthropogenic factors of the structure of the southern taiga forests, industrial cutting is the major one. Although extracted conifer wood does not exceed a half of the allowable cut (Mikhailol 1989), annual extraction of Pinus sylvestris and P. sibirica wood is systematically higher than the norm. On the other hand, only 7 to 10% of the total hardwood is used.

At present, industrial cuts cover more than 50% of the mature and old forest area in the southern taiga zone. Forest use is performed mainly through clearcuts, which are very harmful from the ecological viewpoint (Sushchevsky 1992). Forest fire and insect outbreaks damage southern taiga ecosystems considerably. Gipsy moth and Monochamus urussovi have destroyed over 1 million ha of coniferous forests. Because of anthropogenic influences and biotic factors, mature and old native stands account for only 5-10% of southern taiga forests. In this zone, the area of disturbed non-bogged forests varies with site conditions from 62 to 85%.

The central and southern taiga forest subzones account for only 20% of the total harvested wood. Remoteness of these forests from populated regions, inaccessibility, relatively small proportion of valuable wood, and severe weather conditions - all this put certain limitations on their economic use. Fire is the major factor influencing the current dynamics of these forests. It is widely known (Sannikov 1981, Furyaev 1988, Kuusela 1992, and others) that fires have reoccured many times in boreal forests during the past several centuries. They have caused drastic changes on taiga forest structure. Currently, forest fire danger has greatly increased in Siberia because of the rapid development of mining and oil and gas enterprises in forest areas. Today, fire coverage amounts to 0,7-0,8% annually, which is attributed to summer droughts, high fuel accumulation due to slow mineralization under cold conditions, rapid snowmelt and drying of ground cover, and poor fire protection in these regions (Kurbatsky 1980, Valendik 1980, Sofronov and Volokitina 1990). Frequent fires disturb normal forest regeneration process by hampering it at early and intermediate succession stages.

Forest fires have catastrophic effects on forests of the permafrost zone. Under these conditions, the soil layer inhabited by tree roots is very shallow. Surface fires destructing upper soil horizons result in high mortality rate of trees. A map analysis shows that fire accounts for 35% of ecosystem disturbance in central taiga forests.

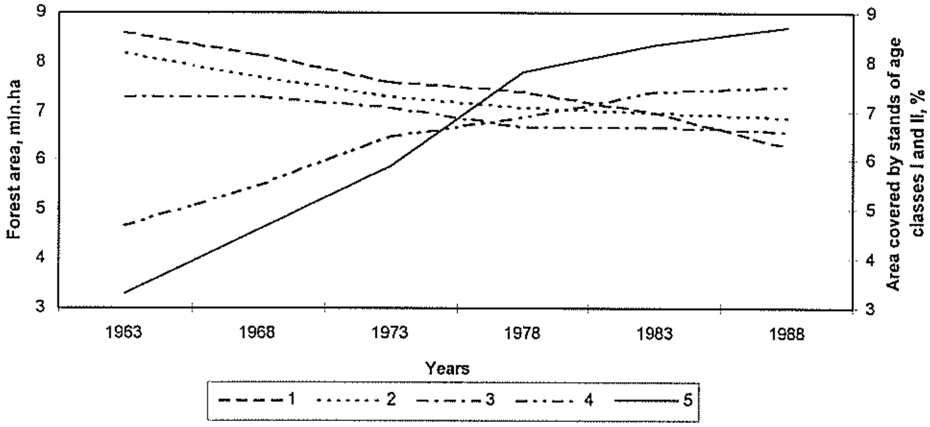

Figure 2. *Changes of forest composition and age structure during 25 years. 1) fir stands, 2) Pinus sylvestris stands, 3) P. sibirica stands, 4) small-leaved stands (birch and aspen), 5) young and middle-aged stands (1-20 and 21-40 years old, respectively).*

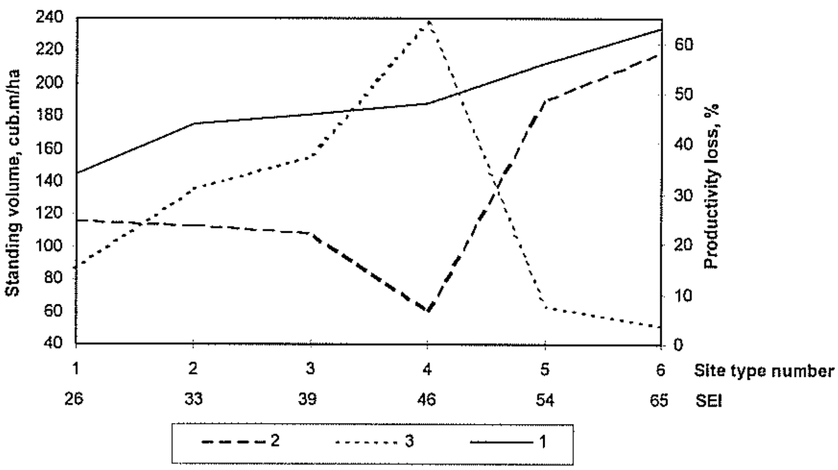

Figure 3. *Influence of cuttings on ecosystem productivity parameters. 1) Maximum possible standing volume, 2) actual standing volume, 3) productivity loss.*

Vegetation cover of forest-tundra and northern taiga zones is polluted by Norilsk mining industry complex. Over 2 million tons of dust and gases are annually released by this complex into the atmosphere, of which sulfur dioxide accounts for 98%. The polluted zone extends for more than 200 km from Norilsk in the southeastern direction. Forest cover is completely killed or heavily disturbed in the area of about 500.000 ha. And the area covered by partially degraded forest is several times as great (Makhnev and Menshchikov 1994). The total disturbance of forests in this region due to industrial pollution, grazing animals, and prospecting is 40%.

Some 15% of mature stands are cut in the mountains of the southern part of Central Siberia. The mean annual fire coverage does not exceed 0.3% of the total area. A great part of mountain dark coniferous forest has been damaged by gipsy moth during the past 50 years.

The results of multiyear forest inventory data available for Central Siberia were used to track the dynamics of forest composition and age structure for the period from 1963 to 1988 (Fig. 2). The area of fir stands had decreased by 23% during the 25 years. After fires, cutting, and biotical events, fir stands are usually replaced by secondary small-leaved forest. Pine forest occupies poorer sites, where stand replacement due to external factors occurs much more rarely. This accounts for the fact that pine forest area decreased by only 14% during the period of time in question. The area covered by small-leaved species increased by 60%. Development of the second tree layer composed of coniferous species is currently observed for 57% of the total area.

In forest cover, the proportion of young and middle-aged stands increases with the degradation of mature and old stands. This leads to changes in the genetic fund of forest phytobiota through recombination of its species composition, flora, fauna, and genetic diversity. Ecological role of forest cover in biospheric processes decreases as a result of its destruction-caused rearrangement. Virgin forests only slightly influenced by man are known to best perform their environmental functions (Mikhailol 1989, Sushchevsky 1992).

To prevent negative anthropogenic effects on taiga forests, radical improvements on the system of forest protection from fire and insects are needed, along with practical introduction of sustainable forestry methods. According to Sochava (1962), at least 30% of Siberian taiga forests should be left untouched. Reimers and Stilmark (1978) believe that in order to support forest ecosystem stability, about 50% and 80-90% of forest cover should be maintained in their natural state in southern and northern taiga zones, respectively.

Methods of detailed estimation of current forest cover changes were tested in southern taiga forests of Central Angara region, which have beendisturbed by fire and cuttings.

Resource and ecological functions of forest are closely related to organic matter concentration in the canopy. Productivity process is quite sensitive to external influences, and its parameters can thus be reliable indicators (descriptors) of ecological forest community state (Baburin 1984, Antanaytis 1983, Utkin 1986).

At the local level, forest productivity is controlled by soil-ecological resources.

Six types of site conditions were identified in a sample site, and SEI values were obtained for each site using a closed 100-unit scale. The analysis of data presented in Fig.3 has revealed that actual standing volume is notably lower than the potential volume under all site conditions. The decrease in forest productivity is caused by changes in the size of forest area and stand age structure, composition and density. The biggest wood losses (67%) are characteristic of moderately rich soils (SEI is 46) covered by pine stands. These stands were intensively exploited during the past several decades. Polydominant dark coniferous stands growing under site conditions of types 5 and 6 are only lightly affected by fire and cuttings. Forest productivity loss totals 36% in the sample site under consideration. This suggests a moderate rate of degradation that does not cause extreme damage to ecological forest functions.

A prediction of the rate of forest recovery back to its initial state requires a study of the rates of both succession changes and stability of vegetation communities within each succession stage. Based on coefficients of similarity of stands having succession stages with succession-free stands of the same dynamic series, rate of succession was calculated for a variety of site conditions (Lopatin 1972). For poor soils, species composition of mature stands was determined to recover by 80-90% a hundred years after their destruction. As for rich soils, the value does not exceed 60-70%, even at the stand age of 180. This suggests a slower rate of succession.

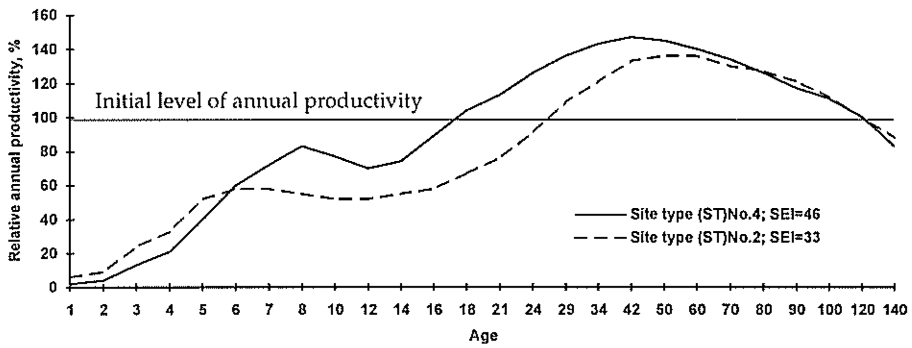

Figure 4. ***Productivity regeneration dynamics of vegetation communities in cut pine forests.***

A comparative analysis of the stabilizing effects of stand differing in age on the environment was based on their annual productivity. Fig.4 shows dynamic curves of annual productivity increment of regenerating ecosystems (overstory, regrowth, understory, and brush and grass layers) obtained through correcting values of this parameter, smoothed over time axis, for its values measured in mature (120-yr-old) stands. According to the curves, annual productivity was established to require 17-25 years to recover to the original level after cutting. It is noteworthy that productivity parameters of vegetation communities differing in age reach similarity earlier under rich site conditions (i.e. on rich soil). After 25 years, productivity of new forest colonizing cut areas appears to be on average 20-30% higher than that of a mature forest. The obvious slowing down of the annual productivity regeneration rate back to the initial level observed for 6 to 15-yr-old stands is attributed to a sharp decrease in the grass layer productivity during the period of canopy closing.

An example of map-based, large-scale inventory of the ecological state of coniferous stands in the forest-steppe zone in the south of Central Siberia is presented in Fig. 5. Soil-vegetation complexes identified within types of site conditions were taken as elementary basic contour units of the ecological map. These contours show thelimitation of forest types to certain geomorphological conditions. For each contour of the map, integral environmental parameters are given (SEI and average stand height at the age of 100), along with vegetation state parameters (actual phytomass amount) and the level of realization of available site resources by vegetation communities.

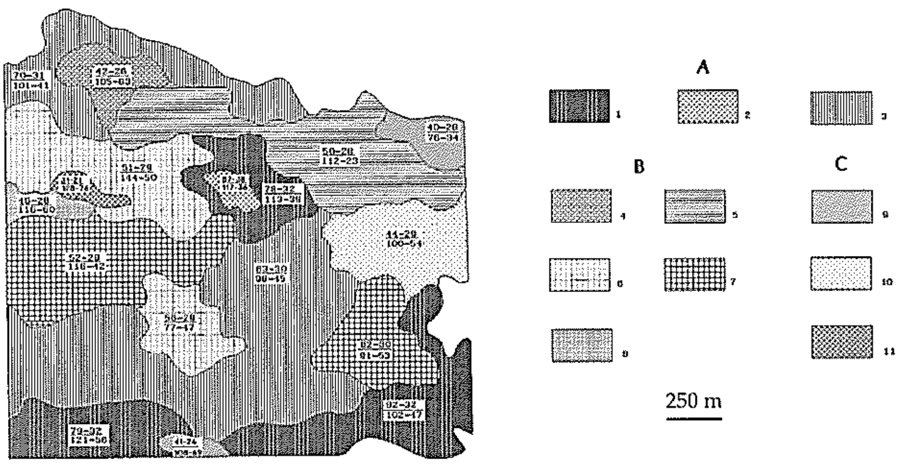

Figure 5. ***Ecological map of pine stands in the forest-steppe zone (a fragment).***
A, B, C - types of site conditions;
1-11 - soil-geobotanical complexes characterising forest type limitation to certain soil-geomorphological conditions;

$$\frac{34\text{-}24}{130\text{-}81} - \frac{\text{soil-ecological index - stand height at the age of 100, m(potential productivity)}}{\text{actual productivity, ton/ha - realisation of site resources by vegetation, \%}}.$$

In natural phytocoenoses, forest stands try to fully use available environmental resources. The stand productivity level is in fact the result that shows combined effects of both natural and anthropogenic factors (Abaturov 1979). Therefore, one can estimate forest cover disturbance when comparing the actual and maximum phytomass of vegetation communities in sites with relatively similar SEI values.

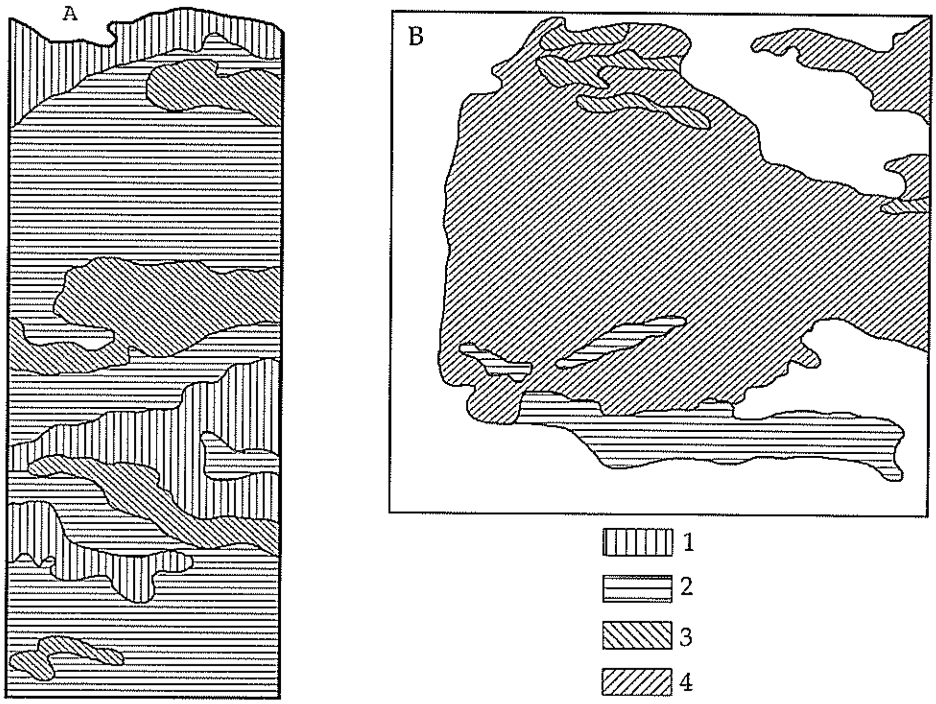

Figure 6. 1:25 000 map of pine stand disturbance in the (A) forest-steppe and (B) steppe zones (fragments). 1-4 are disturbance levels; realization of site resources by forest stands: 1) 20-40%, 2) 41-60%, 3) 61-80%, 4) 81-100%.

Current forest ecosystem state is mapped based on an ecological map and using coefficients of realization of site resources by vegetation (Fig. 6). Four classes of ecosystem disturbance were determined, with the interval being 20%.

The analysis of our map of the ecological situation in the stands of the forest-steppe zone shows that the highest disturbance level is characteristic of phytocoenoses developing under rich site conditions (SEI is 72-95), where vegetation uses only 38-56% of soil-ecological resources available. As for poorer site conditions, coefficients of resource realization amount up to 80-95%. Differences in the level of productivity disturbance are related to forest use policies. Highly productive stands are more often subject to intermediate cut. Moreover, pine stands located along Yenisei river, which are remarkable for the lowest productivity, constitute a part of the water protection zone. Degradation of these stands is considerably lower due to strict limitations of their exploitation. The level of correspondence of productivity parameters with available site resources observed for these stands is thus much higher than in the rest of the area.

4. Conclusion

Intense anthropogenic influence on forests of Central Siberia is accompanied by large-scale changes of their structure, composition and productivity. The level of forest cover disturbance varies depending on the natural zone and accessibility of a forest area, population density in it, and its amount of valuable wood. In industrially developed regions, cuttings, fire and other factors have caused stand replacement in rich soil sites and promoted young and middle-aged stands. Intensive transformation of forest ecosystems leads to considerable losses in their productivity and changes the environmental role of forest. As is obvious from the rate of annual increment of ecosystem productivity, cut or burned forest areas need 15-20 years to recover their ecological properties back to the initial state.

The obtained data on Central Siberian forest cover disturbance and current forest ecosystem state can help in refining existing estimates of the role of Siberian forests in ecological cycles of various scales and modeling the influence of their future dynamics on global climate changes.

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Panel Session

Global Resource Assessment Beyond 2001

Moderator: *H. Gyde Lund, USA*
Rapporteur: *A. Singh, UNEP GRID, USA*
Panel members: *J.P. Lanly, FAO, Italy*
Sumahadi, Ishak, Indonesia
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GLOBAL RESOURCE ASSESSMENTS BEYOND 2001: AN INTRODUCTION TO THE PANEL

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Abstract

This paper lists the inventorying and monitoring needs resulting from various international agreements reached at the United Nations Conference on Environment and Development (UNCED) held 3-14 June 1992 in Rio de Janeiro, Brazil and since then. The documents reviewed include: the Rio Declaration on Environment and Development (Rio Declaration or RD for short); A Programme of Action for Sustainable Development for Now Into the Twenty-first Century (Agenda 21 or A21); Non-Locally Binding Authoritative Statement of Principles For a Global Consensus on the Management, Conservation and Sustainable Development of all Types of Forests (Forestry Principles or FP); United Nations Convention on Biological Diversity (CBD); the United Nations Framework Convention on the Climate Change (Convention on Climate Change or FCCC); the United Nations Convention to Combat Desertification in Those Countries Experiencing Serious Drought and/or Desertification, Particularly in Africa (Convention on Desertification or COD) and the Statement on Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests (Santiago Statement or SS). In addition, there are data requirements needed to complete Global Assessments that the United Nations currently conducts. These new requirements should influence how we conduct inventories in the next century. Our panelists will present their views on how future assessments should be conducted.

Keywords: Global assessments, resource inventory, monitoring

Introduction

Nearly all national natural resource issues, whether they be environmental, social, economical, ecological or political, are also global issues. For these reasons, there is an increasing need for the inventorying and monitoring of our lands and waters and the sharing of the resulting information with the international community especially through the United Nations (UN). Past Global Assessments were sectorial oriented, but recently some new global needs have emerged that may change the way we approach global assessments in the next century.

New requirements

In June, 1992, the United Nations Conference on Environment and Development (UNCED) met in Rio de Janiero, Brazil. Included at UNCED were a number of "Agreements" (principles and statements) and "Conventions" (e.g., international agreements) negotiated related to the environment that add to the information required from national inventory programs. These include the:

<u>UNCED Agreements</u>

- Rio Declaration on Environment and Development (Rio Declaration or RD for short);
- A Programme of Action for Sustainable Development for Now Into the Twenty-first Century (Agenda 21 or A21);
- Non-Locally Binding Authoritative Statement of Principles For a Global Consensus on the Management, Conservation and Sustainable Development of all Types of Forests (Forestry Principles or FP);

<u>Conventions</u>

- United Nations Convention on Biological Diversity (Convention on Biodiversity or CDB);
- United Nations Framework Convention on Climate Change - (Convention on Climate Change or FCCC);
- Since UNCED, a United Nations Convention to Combat Desertification in Those Countries Experiencing Serious Drought and/or Desertification, Particularly in Africa (Convention on Desertification or COD) has been agreed upon.

The Santiago Statement

In addition to the above conventions, a Convention on Forests was more problematic - hence, the final agreement reached at UNCED was the "Forest Principles" on what attending nations could affirm regarding the global concerns on forests and guidelines for how nations would approach sustainable development. Since Rio, nations have been working toward assessing their progress with Agenda 21 and much attention has been given to the measurement of sustainable forestry (e.g., the criteria and indicators for measuring). Sustainable forestry meetings have been held in Montreal and Helsinki.

The agreement for what the international criteria and indicators for the United States is given in the Statement on Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests (Santiago Statement or SS) - signed recently in Chile by North American countries. Similar statements are being developed in other parts of the world.

Global Assessments

Regardless of UNCED, the Conventions, and the Santiago Statement, the United Nations currently conducts at least three Global Assessments:

1. Those directed towards Agriculture - the main one would be the Food and Agriculture Organization's (FAO) Agriculture: Towards 2010. FAO also periodically produces: Commodity Review, State of Food and Agriculture, Animal Health Review, and the FAO statistical yearbooks, viz; Production, Trade and Fertilizer Yearbooks. In addition, there are " Food Balance Sheets " published around every 2 or 3 years. All this statistical information are found in/on "FAOSTAT" diskettes which are available from FAO (Gillin 1995).
2. The Global Forest Resource Assessment (FRA), produced every 10 years by FAO and the Economic Community of Europe (ECE).
3. The United Nations Environment Programme (UNEP) Global Assessment of the Status and Rate of Desertification produced in 1977, 1984, and 1991.

Each of these assessments are on going and all require periodic and specific input from participating Governments. As the Conventions are implemented there probably will be Global Assessments for Climate Change and for Biodiversity.

Commonalities

Basic to the majority of these documents is the national need for:

a. Meeting the social, economic, ecological, cultural and spiritual needs of present and future generations.
b. Providing reliable data and information and to collaborate where necessary, with relevant international organizations, undertake to improve data and

information continuously and to ensure its exchange.

c. Strengthening information, systematic observation, and assessment systems for environmental, economic, and social data related to the various resources at the global, regional, national and local levels.
d. Collecting, consolidating and exchanging existing information and establishing baseline information on aspects relevant to the program area including:
    - Meteorological, hydrological and physical data - A21/13.7(a)
    - Data on natural resources relating to food and agricultural production and planning - A21/14.1(b)
    - Terrestrial, aquatic, and coastal and marine environments data - A21/15.6(c)
    - Assessment and management of coastal areas and all seas and their resources - A21/17.8(a)
e. Gathering multi-sectoral information (forest, wildlife, soils, water, etc.) and integrating the data from these sectors with adjacent areas. Developing integrated information systems for environmental monitoring, accounting and impact assessment.
f. Harmonizing the methodologies for programs involving data and information activities to ensure accuracy and consistency and using compatible standards and systems.
g. Involving the local population in the data collection process.
h. Enhancing research support and improving public access to information.

Areas to be monitored

The areas to be monitored include:

Low-lying coastal areas - FCCC4.8(b)
Arid and semi-arid areas - FCCC4.8(c))
Areas suitable for reforestation - FP6(d)
Areas suitable for afforestation - A21/11.4(a); FP6(d)
Areas prone to natural disasters - A21/13.7(c); FCCC4.8(d); SS3.3a
Areas liable to drought and desertification - FCCC4.8(e)
Areas of high urban atmospheric pollution - A21/13.7(d); FCCC4.8(f); SS3.3b
Areas with fragile ecosystems, including mountainous ecosystems -FCCC4.8(g)
Forested areas and areas liable to forest decay - A21/10.11(d); 13.7(b); FCCC4.8(c); FRA

* Available for timber production - SS3.2a
* Subjected to levels of specific air pollutants (e.g. sulfates, nitrate, ozone) or ultra violet B -

* With diminished biological components - SS3.3c
* With significant soil erosion - SS3.4a
* Managed primarily for protective functions. e.g. watersheds, flood protection, avalanche protection, riparian zones - SS3.4b
* With significantly diminished soil organic matter and/or changes in other soil chemical properties - SS3.4d
* With significant compaction or change in soil physical properties SS3.4e
* Experiencing an accumulation of persistent toxic substances -SS3.4h
* Managed for general recreation and tourism - SS3.6c
* Of plantations of native and exotic species - SS3.2c
* By forest type - SS3.1a
* By age class or successional stage - SS3.1b
* By protected area categories - SS3.1c

Data to be collected

In addition to listing the areas to be surveyed, the Agreements, Conventions, Statement, and the Assessments each require governments to collect specific data. Indicators to be inventoried and monitored include:

Biomass - A21/11.4(a)

Total forest ecosystem biomass and carbon pool (SS3.5a), and if appropriate by forest type, age class, and successional stages.

Climate - A21/10.11(d)

Ecosystems and habitats - CDB7(a)1

Emissions by sources and removals by sinks of greenhouse gases - FP2(a); FCCC4.1(b); 2(c); 7.2(d); 12.1(a)

Contribution of forest ecosystems to the total global carbon budget, including absorption and release of carbon (standing biomass, coarse woody debris, peat and soil carbon) - SS3.5b

Employment - FP2(a)

Energy - A21/12.29(b)

Fragmentation of forest types - SS3.1e

Fodder - FP2(a)

Food - A21/12.29(b); FP2(a)

Fuel - FP2(a)

Land cover - A21/11.4(a); FRA

Land degradation - A21/14.47(b); COD16

Land (?) productivity - A21/11.4(a)

Land use - A21/11.4(a); FRA

Landscape diversity - FP2(a)

Medicine - FP2(a)

Minerals - A21/12.29(b)

Non-wood goods and services - FRA

  Annual removal of non-timber forest products (e.g. fur bearers, berries, mushrooms, game) - SS3.2.e

  Value and quantities of production of non-wood forest products - SS3.6b

Plants and animals - A21/12.29(b); 13.7(b)

  Threatened, cultivated or otherwise useful species and communities - A21/11.4(a); 13.7(b); CDB7(a)1; SS3.1

Recreation - FP2(a)

Shelter - FP2(a)

Soils - A21/10.11(d); 12.29(b); 13.7(b)

Water - A21/12.29(b); 13.7(a); FP2(a)

  Water use - A21/13.7(b)

  Stream kilometers in forested catchments - SS3.4c

  Percent of water bodies (e.g. stream kilometers, lake hectares) with changes in water quality in forested areas - SS3.4f&g

Wildlife - A21/10.11(d)

  Wildlife habitats - FP2(a)

Wood stocks, growth, production, and removals - FP2(a); FRA

  Value and volume of wood and wood products - SS3.6a

  Total growing stock of both merchantable and non-merchantable tree species - SS3.2b

  Annual removal of wood products - SS3.2d

The above list does not include the data required for the current FAO Global Agriculture Assessment and UNEP's Global Assessment of the Status and Rate of Desertification. These will undoubtedly expand the list of variables one needs to track at the national level.

Panel assignments

The information required as a result of UNCED, the recent Conventions, the Santiago Statement, and for the various Global Assessments should influence our resource inventorying and monitoring activities. If we are to take our international commitments seriously, we must build the ability to provide the required data into our national programs.

Given this very short introduction, I will now turn the floor over to our distinguished panelists representing the United Nations, the remote sensing community, individual nations, and agriculture/forestry interfaces. The objectives are to determine what information will be needed in beyond the year 2001, how it will be gathered and how it will be used. Specific questions panelists have been asked to address include:

1. What should the scope of future global assessments be? What are the global threats or concerns - Politically, environmentally, ecologically, economically, and socially? Should future assessments cover forest lands or all lands and why?

2. What information is needed to make better policies and decisions and why? What are the variables needed for different decision-making purposes? What is the spatial resolution required for them (country-county-commune-10 sq. km, 10 ha, 1 ha or less)?
3. What are the possibilities to actually collect and organize this information?
4. What are your visions for how the global assessment should be collected? How should data be collected, who should do it, and how should the data be made available? What should the roles of the following be: Research and the remote sensing community, nations, NGOs and others, United Nations?

Each panelist will have 15 minutes to present his or her views. We will then open the session to questions from the floor. Our rapporteur will try to capture and summarize the resulting recommendations. These will be published in the proceedings of this session. And now our first panelist.

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GLOBAL RESOURCE ASSESSMENTS BEYOND 2001

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Abstract

Sustainable management of global resources for the benefit of people requires suitable, up-to-date information on the state, extent and distribution of the resources. Currently, the information of the global resources is believed to be poor, so that it is felt that any effort should be taken to assess and monitor the global resources at local, national, regional and global levels. The resulting information can be used by policy makers as a basis to make appropriate decisions on managing the resources sustainably.

The global resource assessments in the 21st century should include not only a single factor, such as forest resources, but include also any other factors such as biodiversity, air, water and land cover. The future allocation of the resources should be concerned with the needs of growing human population.

As part of the effort to collect global resources information, the Ministry of Forestry of Indonesia is conducting a national forest inventory (NFI) project. The project includes forest resource assessment and monitoring, digital image analysis system and geographic information systems. The resulting data have been filed digitally and in the form of hardcopies (reports and maps).

Indonesia which has already had a forest data base could contribute to the global resources data base which should be developed and organized by an international organization. On the other hand, Indonesia can also have benefits by having access to the global resources database for various purposes.

1. Introduction

Before discussing further the global resource assessments, we should define first what an assessment is. According to Lund (1993) an assessment is the act of officially estimating the value or character of property. It will include the process of estimating or determining the significance, importance or value of world resources. The year 2001 is just an artificial point, a landmark year, marking the official start of the third millennium.

Why should we assess the global resources? Rodenburg (1992) stated that the state of global information was so poor so that he encouraged people and decision makers to conduct global resources monitoring and assessment. Further Giri (1995) states that agenda 21 of the United Nations Conference on Environmental and Development (UNCED) in Rio de Janeiro (1992) mentions that environmental and multisectoral information is required to be analyzed and used for the decision making process especially in developing countries. Besides that, the threats to global resources are increasing, especially those that are due increasing population so that the resources are more and more decreased and endangered. The most obvious example are the threats to forest lands that come from increasing urbanization so that the forest lands are increasingly converted to agricultural lands or settlements.

We should conduct assessments and monitoring in order to present factual information on the state and condition of resources. The information is required, ultimately, to inform citizens and to foment action by national and international policy makers that will lead to sustainable development and wise management of the world's resources.

Currently the global resource assessments are focussed on single sectors such as forest lands. However, according to Lund (1993) the scope of global resources assessment beyond 2001 should include not only forest lands but also:

- everything in 1990 Global Forest Assessment including : grasslands, agricultural lands, wetlands etc.
- estimation of food, fuel, shelter, employment
- environmental and social considerations in addition to economic factors
- human impact on the earth's resources
- latest technology in data acquisition and display
- present facts including maps showing:
    * distribution of earth's resources
    * distribution of people, agricultural lands, forest lands, etc.
    * current land cover of the earth, including agricultural, forest, urban, grasslands, waterbodies, and wetlands
    * where pressure exists and predictions of where they will occur in the future
    * where opportunities are for meeting needs.

By the availability of global resource information from different sectors we can expect that the future allocation of resources meets the needs of growing human population and also the planning of the different uses on the same area (by different sectors) can be avoided or at least can be made in a better harmony.

2. *The information needs*

To make better policies and decisions, the policy makers and public require regular analyses and assessments of the global resources. According to Rodenburg (1992) some important issues for which policy makers require more or better global information include:

- climate change (average temperature, pack ice thinning, glacier movements, sea level changes, etc.)
- land degradation (salinization, waterlogging, erosion, etc.)
- land use (expansion or abandonment of cropland, intensification, etc)
- vegetation changes (increases or decreases in photosynthetic activity, removal of native climax vegetation, etc)
- water quality and quantity (pollutants, thermal pollution, flows, etc)
- air quality (pollutants)
- human health (pathogens, child nutrition, immunizations, etc)
- population movements (domestic and international)
- ecosystem health (changes in the mix of wildlife, exotic introductions, fragmentation, etc.)
- forest health (deforestation, degradation, fragmentation, degree of exploitation, degree of management, etc)
- faunal populations and health (number of species, number of each species, predator/prey ratio, etc.)
- energy use (amount, kind, alternative uses, etc).

Lund (1993) reports the various parameters of interest to forestry resulting from five workshops on future global forest assessments held by IUFRO, WFW, UNEP/FAO, WRI, and FAO/ECE, including :

a. Stocks/harvest	:	land cover, vegetation type, biodiversity, biomass, soils, watershed/hydrology, fauna, topography.
b. Functions	:	land use, ownership, accessibility, greenhouse gases, carbon storage, burned areas/fires, fragmentation, logged areas, ecofloristic zone, socio-economic.
c. Quality	:	forest health, soil productivity.
d. Other lands	:	agriculture, settlement, industries, etc.

Further, Lund and Gibson (1995) anticipate the rates of the demand for the environmental information as shown on table 1. The highest rating shows the greatest demand for the environmental information.

Table 1 . Anticipated future information needs

Information needs	*Rating*
Land cover	15
Biodiversity	15
Biomass	12
Land use	12
Forest health	12
Socio-economic	11
Vegetation type	9
Carbon storage	9
Ownership	7
Soils	7
Ecoflorostic zone	6
Soil productivity	6
Fragmentation	5
Watershed/hydrology	3
Topography	2
Fauna	1
Accessibility	1

3. *Sources of information*

Information about global resources can be collected through various sources of information such as maps, remote sensing and field information (Päivinen et al.1994). Another source of global information is the literature including reports, journals and newspapers..

Maps of global resources are widely available. The scale, date, contents and accuracy may vary, but they provide a framework for planning the assessment activities. Data analysis can be done at the simplest level by comparing and combining the map of interest manually or, more efficiently using computers. Analysis of the mapped data using a computer in a system called Geographic Information Systems (GIS) is more efficient and gives improved capability.

Using remote sensing techniques, the global resource data can be collected through aerial photography or satellite data. Resolution of aerial photographs permits very detail analysis of the earth surfaces. However, the choice of scale must be tailored to the purpose of data collection and mapping.

AVHRR or NOAAA data with 1-km resolution can be used for an overview at the continental scale with reasonable accuracy. Forest and non forest and other coarse classification is possible to be detected using this satellite data.

For forest and other general cultural features assessment and monitoring the MSS (resolution of 79 m), TM (resolution of 30 m), and SPOT (resolution of 10 and 20 m) are recommended. However, the use of these data especially in tropical countries are often hindered by cloud cover. Hence, in tropical countries, the use of RADAR data, which is free from cloud cover, is encouraged. Unfortunately the technology of using the RADAR data is not widely known yet, so that the transfer of technology in this field from the advanced countries to the developing countries is also encouraged.

The use of remote sensing data (aerial photographs and satellite imageries) is usually combined with field data collection. The purpose of field data collection is collecting data not available from remote sensing data such as stem diameter, soils, etc, and calibrating the results of interpretation. The field plot can be established temporarily, if measurement on the same plot is not necessary, or permanently, if remeasurement is necessary.

The literature, including reports, journals and newspapers, of global resources are currently widely available in bookstores or libraries in many countries. One source of the global literature is the FAO which has published many guidelines and reports on the results of global research.

4. The global resource information users

Among the target users of the global resources information three main groups may be distinguished (Janz 1995) :

- Planners and decision makers in various sectors. The information is useful in national planning such as in forestry since knowledge about the forest situation in other countries influences national strategies; and for international organizations and multilateral and bilateral agencies involved in development cooperation.
- The scientific community including universities and national and international research teams. The knowledge about the state and condition of global resources are very important for the scientists to conduct research for the benefit of human being.
- The public at large. For the public the global information is important as a base to act and to show the wishes to the national and international policy makers to sustain the global resources for current and future generation.

5. *Level of information*

There are three basic levels where global information needs to be assessed, the local, national, and regional and global levels. The resulting information should meet the demand by researchers, public and policy makers mentioned above.

At the local level like provincial or regency levels the global resources assessment should be directed to the local resources that have directly affected the life of the people in and around the area. In forestry the information is needed for the intensive management of the forest such as soil quality, land use patterns, and vegetation types.

At the national level, sustained utilization of the global resource in a country is of primary concern. The resource information here should come from the local level, and the information from national level should go to the regional or global level. On the other hand, the national organizations will receive analysis, information, training and support from regional and global centers.

Regional and global resource information is assembled from national data. The data may be collected through the regional organization first and then sent to the international organization, or directly organized and collected by the international organization. It is up to nations to act and fund the creation and expansion of international bodies and networks to assemble policy relevant data for the potential management of the world's environment (Rodenburg 1992).

Data reported by one country should be defined and classified according to the guidelines made by the international organization such as FAO, UNEP, etc. so that they may be compared, assembled and used as regional or international information to make the management policies at the corresponding levels.

Non-governmental organizations (NGOs) in many countries can serve as controllers or pressure groups to the government policies, but usually they have limited resources. The existence of the NGOs should not be considered as an opponent but on the contrary, they should be considered as partners to make and to implement policies on environmental and global natural resources.

6. *Future directions*

Environmental resource assessments should be conducted either at the local, national, regional and global levels. If there are no relevant institutions in a country, it could be created to take the responsibility for environmental monitoring and assessment all levels (depending on the country's resources). The funding should be provided by the country itself, by donor countries, or by international organizations.

The database should be constructed nationally, regionally and globally. Government institutions or NGOs can have access to the database, so that resource information can be disseminated and communicated to the world at large. The analysis of the database for scientific or specific research relevant to specific questions must be encouraged and funded. One thing that should not be forgotten is the quality control for the disseminated data, so that the accuracy and reliability of the data can be maintained.

7. Forest resource monitoring and assessment in Indonesia

One of many efforts in Indonesia to assess and monitor global resources has been performed by the Ministry of Forestry of Indonesia through the National Forest Inventory (NFI) project assisted by the consultants assigned by the FAO.
The immediate objectives of the NFI project are :

a. To develop and implement a cost assessment system which will :
   - provide information on the location and extent of the main forest and land use types;
   - estimate volume and growth by forest type, species and marketing group;
   - assess the state of forest areas and assess genetic diversity.
b. To develop a system for the continuing assessment of the forest change;
c. To develop local staff capability so that the system can be managed and operated by the staff of the Ministry of Forestry.

The main activities of the NFI project include :

- Field data systems (FDS) including: (a) forest resource assessments (FRA) by means of enumerating data from temporary sample plot (TSP), and (b) forest change monitoring by means of checking and renumerating permanent sample plot (PSP) repeatedly at a regular basis.
- Remote sensing systems including: (a) forest resources monitoring by the means of wall to wall mapping of forest area based on remote sensing data, and (b) forest change monitoring by the means of the analysis of multidate remote sensing data.
- Geographic information system (GIS), integrating all relevant data and information to produce forest resource maps and statistics in a geographical data base.

Field data are taken from cluster sample plots distributed systematically on a 20 km grid all over Indonesia (except Java island). A TSP cluster that consists of 3 by 3 or 9 square tracts of 100 meters in size and 500 meters in span is used to assess the standing stock. In each tract, at 8 points around the sides (at the four corners and at the mid point of the four sides) a sub plot of point sampling with BAF 4 is made. The center tract of TSP cluster serves also as PSP which is divided into 16 record units (25 by 25 meters), where repeating measurements at different time are made. The set of sub plots includes various radius of sub plots for enumerating seedling, sapling and poles to assess the potential regeneration of the forest area.

The spatial and non-spatial data resulted from the project are entered into databases that can be used for forestry decision makers and public and other users to make policies about the sustainable forest management in particular and global resources in general.

The NFI output among others are :

a. *Remote Sensing/Forest Mapping*

   The first round of Indonesia forest cover mapping by means of visual interpretation/classification of 1986-1991 Landsat MSS hardcopies (1:250 000 scale) was completed resulting of 257 map sheets. In this process, 122,5 scenes of MSS prints and 21 TM prints covering about 84 % of the country were interpreted/classified. The remaining 16 % were filled in with information from SPOT, aerial photos and RePPProT maps.

   The second round of forest cover mapping will use digital TM data (1991 to 1995), by means of digital and manual interpretation. This process will up date the maps produced by visual interpretations of the MSS data.

b. *Forest Resource Monitoring*

   Based on the compiled data of Landsat MSS (between 1986 and 1991) visual interpretation, there is approximately 120 million ha (63%) of total Indonesia land covered by forest. The data was generated from the GIS database after all MSS data were digitized. The distribution of forest cover in the major islands are :

Major Island	*Forest cover (ha)*	*% of total land*
Sumatera	23 628 590	49.66
Kalimantan	38 943 650	72.22
Sulawesi	11 378 710	60.80
Maluku	6 411 290	82.47
Irian Jaya	34 966 480	84.71
Nusa Tenggara & Timor-Timur	2 216 130	27.72
Jawa & Bali	3 034 630	22.04

c. *Forest Resource Assessment*

   The major activity of forest resource assessment is to make approximately 3000 cluster plots throughout Indonesia. The progress up to March 1995, includes: 2649 clusters enumerated; 2300 clusters entered into the database; 1885 clusters analyzed; and 1706 clusters out of 1885 clusters used to make interim statistics of forest resources in Indonesia.

The temporary result of the Indonesia forest potency in 5 major islands for all species with the diameter of more than 20 cm are :

Major Island	*Total volume (billions m^3)*	*% of total*
Sumatera	2.1	20
Kalimantan	3.4	32
Sulawesi	1.1	10
Maluku	0.7	7
Irian Jaya	3.3	31

d. Forest Cover Changes

The estimate of forest cover loss in Indonesia was made by Forestry Studies Project (Sutter 1989) giving the rate of deforestation at about 950 000 ha per year during the period 1982 into 1990 excluding the 3.8 million ha "lost" in the 1982 - 1983 forest fires in East Kalimantan. This study confirmed the 1989 World Bank's estimate of annual deforestation in Indonesia as between 700 000 to 1.2 million ha.

Another study of forest cover loss was made by Revilla, Chief of Technical Assistance of the National Forest Inventory Project of Indonesia (1993) using the mosaics of 1:1 million scale Landsat MSS-FCC prints (1986 - 1990) and 1:1 million scale, black and white (Band 5) prints (1972 -1982). In this study, the interpretation was made by manual/visual method. Due to the small scale of the data, the land was classified only to two classes: forest cover and non forest cover.

The result of this study gave a simple estimate of forest cover changes for seven major island groups and for the whole country, as follow :

Jawa	:	2 800 ha
Sumatera	:	345 200 ha
Kalimantan	:	177 300 ha
Sulawesi	:	102 100 ha
Bali/NTT	:	9 100 ha
Maluku	:	36 000 ha
Irian Jaya	:	136 800 ha
The whole Indonesia	:	810 000 ha

Based on these estimates, about 810 000 ha of forest cover loss annually during the period 1972 to 1990 or about 14.6 million ha over 18 year period (Revilla, 1993).

The area of forest cover changes were estimated for:

Agriculture and estates	:	270 000 ha
Transmigration	:	200 000 ha
Industrial forest plantation	:	200 000 ha
Shifting cultivation	:	130 000 ha
Others	:	10 000 ha
Total	:	810 000 ha

These data and information can be contributed to the global data base, considering the sovereignty and the agreed international rule of data exchange. On the other hand the NFI or the other Indonesian agencies should also have access to the global data base for various purposes following the same rule.

8. Conclusions

Information about global resources is poor but obviously there is a need to assess them regularly and continuously. The result of the assessments can be used for making intelligent decisions about wise utilization and sustainable management of the resources at any level of global concern.

The assessments should not be intended to address only the single factor, but they should include also other factors influencing the human life such as climate change, land degradation, vegetation change, etc. By knowing the information of other factors, it can be expected that the wise use of each factor or the combination use of two factors can be considered for the benefit of people.

The sources of global information can be maps, remote sensing data, field information, and literature. The combination use of these sources is recommended to obtain more accurate and reliable information. The level of information may be local, national, and regional or global, depending on the kind of the resources. The source of the data base for the higher levels comes from the lower levels, based on the agreements between the participating countries.

The global information users may be the planners and decision makers, the scientific community, and the public at large. They need the information to make decisions on the wise use and sustainable management of global resources.

Indonesia is one of the countries conducting forest resource assessment and monitoring the resources through the National Forest Inventory Project assisted by the FAO. The resulting data and information have been filed digitally and in the form of reports and maps, ready to be used for the decision making process.

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GLOBAL FOREST RESOURCES ASSESSMENTS BEYOND 2001: INTEGRATED RESOURCE DATABASES - AN EMERGING APPROACH

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Abstract

The demand for regional and global level forest resource assessments has gained momentum during the last decade or so. The primary use of such information is in the formulation of regional and global policies and agreements. Continuing demand for such information is driven by the need to establish the baseline data set, and developing models for resource monitoring. Four main problems are encountered in compiling global information on forestry resources:

- the actual needs and beneficiaries of the information have not been identified. This makes it difficult to define the current knowns and unknowns
- the available data sets have been collected at different times and for different objectives than the intended global uses. In addition, they are highly variable in content, accuracy and precision
- the compilation process takes very long, risking decay of some of the information
- there is no clear division of mandates and obligations among stakeholders

Any future strategy for assessing global resources should first seek to solve these issues. One approach is to work out mechanisms and procedures to harmonise inventory and monitoring objectives at the national, regional and global levels. To achieve that, it is necessary to agree on the division of mandates and financial obligations among the stakeholder institutions. The next step is to consider integration of databases. Ultimately, we have to provide incentives for the traditional timber cruiser to **think globally.** In order to do that, there is a need to study the policies that govern resource endowment.

Keywords: Integrating databases, resource endowment, stakeholders

Introduction

As we unravel the biophysical and socio-economic mysteries of the earth and its people, it is becoming increasingly clear that our interactions with its resources need to be better managed. Biophysical scientists have concerned themselves mainly with detecting, measuring and modelling economically rewarding components of resources and processes. Thus a resource is defined by its worthiness to be measured, modelled and monitored. This "worthiness" differs from place to place and among different cultures. In addition, our approaches in resource information are tailored to respond to narrow disciplinary perspectives. Consequently, available data are highly variable in quality, and in spatial and temporal resolution. These attributes serve to impede database integration. Global consensus on the status of resources and predicted changes have been based on at best, sketchy estimates. Through analysis of the limited information available, it has been possible to infer that actions taken locally can have considerable impact on the regional and global environment. This changes our perspectives on how to manage resources.

During the last quarter of the 20th century mono-disciplinary approaches in resource information have been heavily criticized mainly due to new thinking focused on the survival of the earth as a whole rather than its individual components. This has changed dramatically the system of values. The need for disciplines to work together and to share information has emerged. Similarly, the need for different cultures to work together for better international public goods and services has been accepted at least in principle. This is enshrined in Agenda 21, adopted in Mexico in 1992. This political commitment requires a follow up with the necessary institutional arrangements and allocation of resources for implementation.

As we interpret the new agenda in forestry, we face the following questions:

- who want the information and for what purpose? What are the specific information needs in terms of type, quantity and resolution?
- what resources require assessment and monitoring now and for the future?
- what are the spatial and disciplinary limits to the forester's role in resource assessment?
- what policy and institutional arrangements are necessary for the collection, processing, managing and using information and who pays for it?
- what are the safeguards against abuse?

Various individuals and institutions have been addressing these questions, but with limited co-ordination between them. Fundamentally, information is intended to support decision making. For instance, Grain (1993) recognized the need for an environmental decision support system, but pointed out the major problems and challenges, one of which is the integration and harmonisation of data from environmental and socio-economic sectors. Päivinen et al (1994) and Rodenberg (1992) provided some good ideas on objectives, information needs, data sources, sampling designs and some organizational aspects. Lund (1993) touches on policy and institutional issues.

IUFRO's uniquely neutral status provides the enabling environment for an analysis of the questions raised above. In the subsequent sections of this paper, I will respond to some specific questions, bearing in mind the incompleteness of the questions as well as the answers.

What should the scope for future global assessments be?

At its sixth session in 1951, the Conference of FAO recommended that the organization should collect and publish available information on the world's forest resources at five-year intervals (FAO 1963). The objectives of that effort have not changed much today. They are:

- to provide a complete picture for the resources available and increasingly under population pressure
- to protect wildlife and recreational sites
- to regulate water regime and the environment.

In FAO's world forest inventory of 1963 the difficulty of amalgamating information was pointed out. Today we are talking of the difficulty of integrating databases. In 1963 another issue was concerning the scope of assessments. At that time we were more concerned with geographic and vegetation type limits. Today we have expanded the scope to include other land-use disciplines to differing extents. Resolution of the basic data sets, accuracy, precision and extrapolability of the results bother us now, much as they did in 1963. Fundamentally the issues have remained the same, despite major technological advances.

Changes in the status of global resources are being mediated by both natural and man-made factors. Man-made changes are shrouded in complex social, economic and political environments which are driven by three main forces - business, ignorance and poverty. To reverse the direction of these forces requires changes in the rules and regulations governing resource endowment. Better resource information can create the necessary awareness of the risks to the global community, and catalyze change of attitudes, policies and actions. Information can also provide a platform to negotiate changes in resource endowment and subsequently guide the processes of change for the better. This is why it is necessary to begin by clarifying on information needs before we discuss methods and technologies to collect and disseminate it.

Given the complex interactions among resources, it is hard to define the biophysical or socio-economic limits for our assessments. To be complete, the assessments have to integrate information from the atmosphere, biosphere, geosphere and "sociosphere" (Table 1). For instance, forest resources can no longer be viewed narrowly as occuring only in designated forest areas. There are many activities outside the forest which change the roles of the forest. In many developing countries, local communities still depend on forests for energy and food, and income. Two processes are currently taking root there. The first is adaption and domestication of valuable multipurpose trees. The rubber agroforests in Indonesia, Chagga home gardens in Tanzania and planting of peach palm in Peru are excellent examples of agricultural practices that progressively increase the proportion of the tree component to the extent of making the farm appear to mimic natural forest systems. Similar actions are being adopted in many developing countries, and the net result in the long run may be a reduction of the pressure on existing forests. This shifts the centre of gravity for resource information managers. It is clear that forest resource assessments can no longer be confined to forests or to individual disciplines. A practical approach is to resource assessment is to work with other disciplines and especially to assess resources on farmland.

Table 1. Scope of global resource assessments

Sphere	*Main components*	*Examples of concerns*
Atmosphere	Gases, climatic factors	Ozone layer, carbon dioxide levels, pollution (gaseous and particulate)
Biosphere	Ecoregions, ecosystems, flora and fauna	Food production, forest products, vegetation cover, biodiversity and rates of change
Geosphere	Landscapes, soils, water and minerals	Changes in renewable resources (rates and causes), hydrological cycles, non-renewable resources
Sociosphere	Value systems, Policies, political trends, demographic changes, human activities	Resource endowment, trade, economic development

The demand for separate data to meet the needs of the different disciplines will remain important. Across disciplines, it is necessary to agree on parameters of common interest and to begin with selective integration of databases. This approach is recommended because:

- many institutions involved in resource assessment have little experience working together and integratively. Their separate data require re-organizing and in some cases re-processing to produce desired and compatible information. This takes time and must be executed gradually to minimize errors.

- working with selected information types allows for gradual integration of databases and provides experience in the management of errors
- in relative terms, database integration is more easily achieved at the global level because there, a lower level of resolution can be accepted than at specific sites
- it is necessary to work with national and regional institutions and to enable them to acquire the capacity to collect, process, use and share information

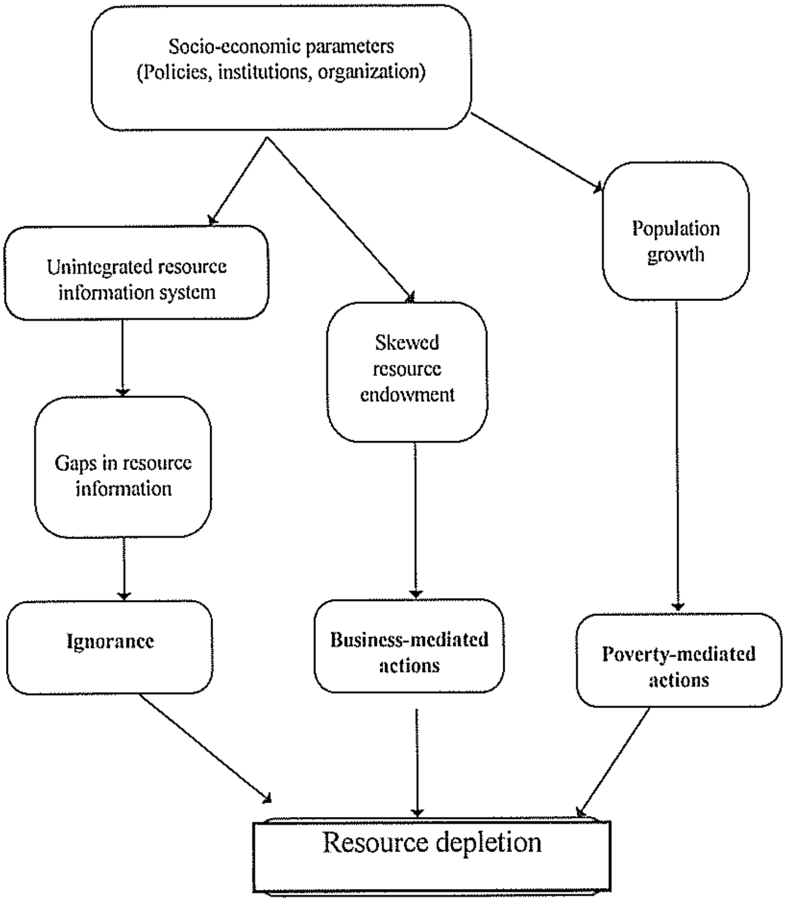

Figure 1. Causes of resource depletion.

Resource information is rapidly becoming an international public good. But we must distinguish between desirable and achievable goals. This is why all stakeholders should be involved at an early stage to work out modalities for funding, managing and controlling resource information. Without such action it is possible to shift resource endowment, in a direction that promotes both business, poverty and further resource depletion. It is clear from this argumentation that social, political and economic imperatives underlay global resource assessments. Knowledge of spatial and temporal distribution of resources is not adequate. The rules and regulations governing resource endowment are important. It is necessary to emphasize here that the key to the survival of any ecosystem lies mainly in a change in resource endowment (Figure 1). It is not practical for me to dwell on how to solve the problem in this treatise.

What information to collect?

First of all we need a clear statement of the information needs, then an assessment of the current knowns and unknowns. Thereafter, two integrative processes are envisaged. The first concerns re-organizing, harmonizing and integrating the existing databases. This should be done first within each discipline (forestry, range, agriculture, marine, etc.) and then across them. The second process is inductive. It concerns the direct acquisition and interpretation of new data. For this, representative sample sites can be selected on ecosystem basis for permanent monitoring. Data from such sites would be useful for cross checking and adjusting similar data from other sources. Socio-economic and political inputs should be incorporated at all stages by stakeholders. This is of vital importance. The process requires a high degree of co-ordination and networking. The fundamental steps are outlined in Figure 2.
Four technical issues have to be resolved:

- compatibility of databases (media and connectivity)
- comparability of information across regions, ecosystems and disciplines
- resolution and error management
- managing retrieval and use

Some of these issues have been raised by FAO (1993) but they remain largely unresolved. The objective of database integration is to synthesize data so as to produce one global resource vision. In resource monitoring, we are interested in measuring the processes of change, their causes and effects. Change takes place in two directions:

Destruction ← **Change** → **Recovery**

To monitor and control change, two approaches are feasible. The first one is to start from very broad platforms; then narrow down to the individual ecosystems and finally to particular sites or plots. Space-borne and airborne platforms can provide information for large areas. Selected sample areas can be measured for ground truthing. There are many examples on the successful application of for instance, stratified multi-stage sampling designs for this purpose. For comprehensive global assessments, it is necessary to collect additional data. To acquire such data may require special institutional arrangements.

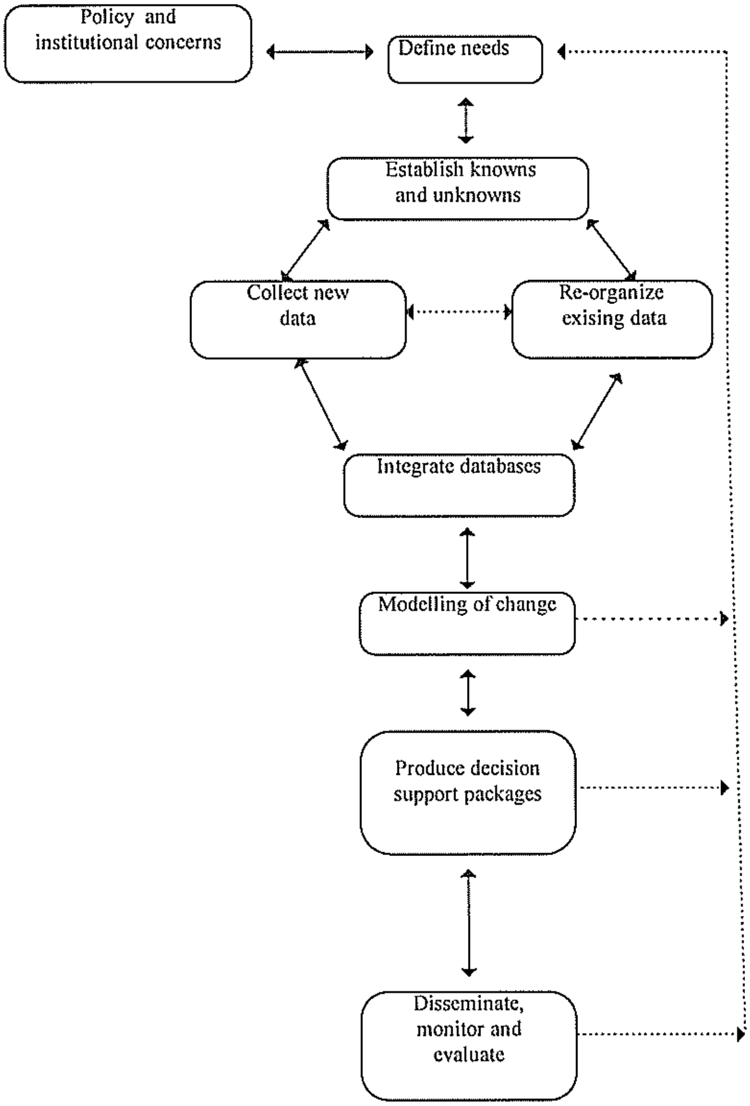

Figure 2. Steps toward global resources assessment.

What are the possibilities to collect and organize information?

I have already mentioned the importance of integrating existing databases. The process involves blending of manual and automated processes as those relating to people, infrastructure, ecosystems, etc. (Lund 1993). This process is difficult but an essential beginning because of the following advantages:

- it builds partnerships among all the individuals and institutions involved. Each individual and institution involved in data acquisition and information management has a role to play to make the global assessment a reality. Sustainability of the system depends on this.
- the process allows individuals and institutions with comparative advantage in a specific area of expertise to take the lead in that area.

Global co-ordination can be achieved through networking. For this purpose, there is a need to form a body responsible for setting standards for data collection, compilation and presentation. Existing institutions such as UNEP, GEF, FAO, IUFRO, WRI and all IARCs especially CIFOR and ICRAF can play a role in this, but they need to be co-ordinated. Remote sensing institutions can provide services and products that enhance the quality of data. There is a need to develop and/or enhance inter-agency and international communication in forestry and related fields in order to achieve our goal. A simple matrix can help to identify the mandates suitable for stakeholder institutions. Table 2 presents an example.

Table 2. An example of the division of mandates among stakeholders

Level of organisation	*Example*	*Mandate areas*
Leading international organisations	CIFOR, FAO, GEF, IUCN, IUFRO, NRI, UNEP, UNESCO-MAB, WRI, WWF,....	· policy and institutional matters methodology development · management of global sample sites · networking
Associated international organisations	CGIAR centres, all research supporting institutions (e.g. Ford Foundation, Rockfeller Foundation, SIDA), botanical gardens, remote sensing centres, NGO's, ...	· expanding databases across areas and disciplines · technology transfer · funding of research · establishment and management of global sample sites
Regional institutions	African Academy of Sciences, ASARECA, SACCAR, Asean Institute of Forest Management, ...	· regional syntheses · policy development and monitoring · database integration · establishment and management of regional sample sites
National institutions	universities, research institutes, NGO's, ...	· data collection and analysis (national sample sites) · education and training · dissemination and monitoring use of resource information

Education and training

As noted by Patel (1993), higher education returns are the very substance of development and progress. For the new vision in forest resource assessment to be sustained, educational and training programmes must be adapted to it. For this to happen, universities and other educational institutions should participate in global assessment efforts.

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GLOBAL RESOURCES ASSESSMENTS BEYOND 2000

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Abstract

The scope of global forest resources assessments beyond 2000 will have to reflect the overall concern of society for a better environment and include an increasing number of variables related to the environmental functions of forest ecosystems. Present and future work on the definition of criteria and indicators of sustainable forest management will be particularly useful in this respect. Future global assessments should concentrate on forested areas but cover all lands with a potential for forest conservation and development, and areas with scattered trees and trees in lines.

Though there is not as yet global forest policies and decisions some progress starting with UNCED (1992) has been achieved in developing international consensus in forest conservation and development. In addition to the results obtained so far jointly by FAO, ECE (UN), UNEP and IUFRO including the inclusion of variables related to climate change and conservation of biological diversity, three types of data deserve particular attention at global level, viz. information on ownership and tenure, detailed information on plantations and state of forest management.

Despite the essential need for comprehensive assessments of the world's forests, available means are still insufficient at national and global levels. While it is important to remain ambitious for the future, it is also necessary to be realistic. Strengthening country capacity in forest assessment and harmonisation concepts and classifications will remain key priorities for many years to come.

Core work should be carried out by the intergovernmental organisations with a global or regional mandate in this field (FAO, ECE, UN, UNEP) in synergy and with the support competent of governmental and non-governmental institutions active at national regional and global levels (including IUFRO, WCMC, Joint Research Centre of European Communities, INPE, NASA).

This panel session offers a most welcome opportunity to brainstorm in a forward looking manner on the contents and modalities of assessment and "systematic observations" of the world's forests. This is particularly timely, three years after UNCED, to demonstrate that forest inventory specialists are concerned not just by the methods and techniques they use, but also by the relevance of the information they generate with regard to the present and expected needs of society at large.

The four questions proposed provide a comprehensive coverage of the issues at state, present some overlap: whenever needed cross references will be made. Moreover the questions refer in part to assessments at lower levels than global: in many ways and with regard to most variables there cannot be global assessments without assessments at national, subnational and management unit levels, hence the difficulty to consider the global level independently from these latter.

1. *First question: What should the scope of future global assessments be? What are the global threats or consensus - environmentally, socially, economically, politically? Should future assessments cover forest lands or all lands and why?*

This fundamental question "sets the scene" and raises very important conceptual issues. It can be divided in fact in two main questions, one related to the thematic scope of future global assessments, and the second one to the lands to be covered.

1.1 Thematic scope of future global assessments

a) Introductory remarks

- There is no clear distinction between the environmental, social, economic and political fields. Society (or rather societies) expresses its needs with regard to forest conservation and development which must be reflected in the design and implementation of forest resource assessments. Political consensus translate more or less these needs in the environmental, economic and social fields ("social" being used in its strict meaning and not equivalent to "societal").
- While it is not too difficult, at least theoretically, to design assessments at national and lower levels to respond to the needs of national and local communities, the matter becomes more complex at global level. National priorities in forest conservation and development are quite different according to countries and depend on their economic, social and cultural conditions.

Clearly, any global assessment is prone to satisfy only partly the priorities expressed by all segments of the world community. If one wants to avoid a global assessment system to become an unmanageable and excessively expensive "monster", compromises will have to be made on the thematic scope, as well as on the spatial resolution and the precision of the information provided. These compromises must be guided by decisions and recommendations adopted at international level, and, particularly, by those made by UNCED (mostly "forest principles" and Chapter 11) and as a follow-up to it (e.g. ecoregional agreements on criteria and indicators of sustainable forest management).

- Diversity of concerns and priorities among countries, and among interest groups at national and international levels, is compounded by the difficulty to figure out what they will be beyond 2001. Projections are available with regard to demographic and socio-economic trends and can be helpful. But they do not tell us really how forest functions will be valued and ranked in, say, 2010 or 2020. Environmental and social functions, including equity in sharing benefits, will most likely continue to be stressed, but to which extent, and how they will be valued in economic terms and combined with the productive functions are subjects which remain largely a matter of speculation.
- Another type of concern or demand is that expressed by the scientific community which goes beyond that of the rest of society in the environmental and economic domains. This is particular true at global level in the whole field of climate change and carbon budget.
- A main issue relevant not only to the scope of global assessments, but also to the three other questions put to the panel is that of the cost effectiveness, and feasibility of collecting additional information to meet all kinds of demands. This fundamental issue is addressed in the comments related to the third question.
- Last, but not least, a comment on terminology. For some time now, the word "threat" has been used too lavishly in relation to forests, particularly at global level. There are undoubtedly at local, national, subregional or ecoregional levels symptoms (or syndromes) of unsustainable use, bad health and poor vitality (diseases, die-back, pests, fires) and evidence of death or destruction (clearing of forests and their replacement by some other land use and/or cover). Some of these problems constitute real threats to the very survival of forests at local or even national level, but hardly any one should be qualified as a threat at global level. More generally, and with higher priority given to forest issues by public opinions and the media, we, as foresters, should be more cautious than before with the terms we use. This is important not only vis-à-vis the rest of society, but also for the development of a consensus in the difficult international debate on forests.

b) There can be no doubt that future assessments - from local to global - should continue to adjust to reflect the overall concern of society for a better environment. This means more work on identification and collection of variables characterising the environmental functions of the forests and describing forests not just as a population of trees, but as ecosystems. At global level, work has been going on for several years under the auspices of FAO, ECE (UN), IUFRO, and UNEP in co-operation with national institutions and non-governmental organisations concerned (e.g. FAO/UNEP Expect consultation on Environmental Parameters in Global Forest Assessments, Nairobi December 1992). At ecoregional and regional levels, considerable work has gone into the identification of indicators of sustainable forest management whose results are of particular relevance for assessments at national and global levels (see also comments on the second question).

c) Work on criteria and indicators of sustainable forest management is also useful for adjusting assessments variables of economic and social relevance and identifying the missing part.

1.2 Lands to be covered by global assessments

a) Introductory remarks

- Reply (or rather replies) to this part of the question is very much dependent on the viewpoint of the users of the information founded:
  - (i) most users are interested by the actual forest cover; however it is important also to know (see (ii) below) about the lands which are presently destined to forest use, for instance "forest lands" belonging to the state which may or may not be covered by forests;
  - (ii) users of the information may be concerned only by the actual use of the lands as forests, or interested also by the potential (ecological and/or economic) use for forest conservation and development of lands which are not presently aimed at forest use;
  - (iii) in many areas (e.g. dry zones, agroforestry landscapes, urban and periurban areas) people derive many of the goods and services provided by forests in other zones from sculptured trees, or trees in lines. Most people would probably argue that forest assessments should also cover these lands.

b) The above considerations tend to demonstrate that global assessments should be concerned not just by lands covered with forests but also by the legally gazette and other "forest lands" which may not be covered by forests, and, more generally, by lands which provide forest goods and services presently (lands with trees) or potentially (e.g. lands which may be abandoned by agriculture and may revert to forest either naturally or through plantations). The total of these lands amount practically to all lands with the exemption of mountainous zones above tree line and wide uninhabited desert areas.

c) However let us forget the main basic "state" objective of global forest assessments which is to answer the following question: how much and which lands are covered by which forests of forest ecosystems on planet Earth? So clearly, global forest assessments must concentrate on the forested areas and provide geographic and statistical information on the extent, at a given time, of forest ecosystems covering the land surface of the earth.

2. *Second question: What information is needed to make better policies and decisions and why? What are the variables needed for decision making purposes? What is the spatial resolution required for them (country-county-commune-10 km², 1 km², 10 ha, 1 ha or less)?*

2.1 *Introductory remarks*

- The wording of the question tends to indicate that it concerns not just global assessments but also assessments at all other levels from local (forest management unit) to regional or ecoregional. At global level, there are not such things as global forest policies and global forest decisions (at least none that are binding for countries or individuals). In Rio, in 1992, for the first time in history a non-legally binding global agreement was reached on forest conservation and development. Even the European Union, one of the strongest regional organisations has not a common forest policy yet. However, the need is felt increasingly for more or less "soft law" at international level in the field of forestry, as demonstrated by agreements reached within the framework of the Ministerial Conferences on Forest Protection in Europe, and by such subregional groupings as the Central American countries or the Amazonian Co-operation Treaty. Progress in this field remains very slow. Since the panel is concerned with global assessments beyond 2001, the words "policy" and "decision" nevertheless have some relevance also at global level.
- As already stressed in the first section, there is an increasing demand for forest information at global level from the international scientific community. Part of the research carried out by this latter will provide results which decision-makers may use in the decades ahead. There is thus a relation, albeit indirect, between global forest information requested by the scientific community and future decision-making. However it is difficult today to assess the relevance

of such information. For instance, though there can be overall agreement on the usefulness of the present research on global change for decision-making in the 21st century, parts of it, or some avenues explored by some research groups on climate change in terms of forest information and its spatial resolution may be far in excess of what is really needed, given in particular the uncertainties and approximations of the models used. Relevance for future decision-making of any demand from the scientific community should not be taken systematically for granted and those involved in the design and implementation of global assessments should exercise their critical judgement in this respect.

- Caution and common sense are the more important in assessing the relevance of requests for information at global level, as any collection or compilation at this level has a significant cost. Also, forest inventory specialists should by now be sufficiently warned against superfluous information. A significant part of results of past inventories from local to national has never been used. Conversely information sought by potential users was not provided, not necessarily for lack of money, but mostly for lack of sufficient consultation with them. Here too, like in section 1, we are faced with the issue of cost-effectiveness of information, which we should touch again in section 3.
- A last preliminary remark on the subject of information relates to the necessary process of continuous adjustment of assessments to changing needs and priorities for information. For instance, FAO (and ECE/UN) adopted their methodology at regional and global levels from 1980 to 1990 to take better into account the increasing concern for the environmental functions of the forests, particularly the conservation of biological diversity and the need for more precise information on the types of changes in vegetation cover for better assessment of the carbon budget.

2.2 *Nature of information needed*

- Most of information needed and the corresponding variables relate to the overall concept of sustainable forest management. During the last five years or so, much work has gone into the definition of criteria and indicators (C and I) of sustainable forest management at various levels. For global assessments, the work done on C and I at national level within the framework of regional or ecoregional processes (ITTO, "Helsinki process", "Montreal process", Amazonian Co-operation Treaty) is most relevant and should be used to the maximum extent possible. Variables to be measured or estimated relate particularly to the six common types of criteria identified by most processes, i.e. extent of forest resources, biological diversity, health and vitality of the forest resource, productive functions of forests, protective and environmental functions of forests, development and social needs.

- As already mentioned work has gone into the defunction of environmental and other variables for global assessments under the auspices of FAO, ECE-UN and UNEP and in co-operation with IUFRO in 1992 and 1993. Work of these organisations continue in this field and an intergovernmental expert meeting is contemplated on this subject for spring 1996 in preparation for the Global Forest Resource Assessment 2000.
- Three categories of variables will deserve more attention at global level than heretofore. The case of those related to ownership and tenure has already been highlighted (end of section 1.1). Given the increasing economic importance of forest plantations, as opposed to more or less manipulated natural forests, estimation of success/survival rates by main age classes and specie groups must be given high priority. Within the framework of a global wood supply study, FAO has embarked on a refinement and updating of the component on plantations of its global Forest Resource Assessment 1990. Finally there is insufficient information on the state and intensity of forest management at subnational, national and global levels, be it for production and/or conservation purposes. Much remains to be done in this respect with regard in particular to forests in the developing world in general, and to private forests in the industrialised countries.

2.3 *Spatial resolution*

- There is not a single answer, nor even a limited number of answers, to this complex question for many reasons. First because the issue of spatial resolution cannot be dissociated from the more comprehensive one of precision, or error, of the information provided. It is of little use to provide geographic information with high resolution if the "attributes" assigned to each pixel have a large margin of error at a given probability level. Moreover, provision of georeferenced information must not detract the responsible person or unit from trying to estimate the precision of the information provided: even "complete enumeration's" in the form of "wall-to-wall" mapping and other georeferenced reports have their systematic (biases) and non-systematic, personal or non-personal errors.
- The second reason why there cannot be a simple answer to the question of spatial resolution is that the required resolution depends not only on the variable at stake, but also on the level and horizon of planning. For a given variable, the general rule will be that the spatial resolution at global level will be coarser than (or equal to) that at required level, itself coarser than (or equal to) that at national level, and so on.
- A third difficulty relates to the definition of required resolution versus that of optimum resolution. Not only should, at least in some cases, the level of

required spatial resolution be critically reviewed by the assessment specialist unit and discussed with him/her, but also the feasibility and cost-effectiveness of this requirement should be evaluated and an optimum spatial resolution be determined which may be coarser than the required one.

- The optimum spatial resolution for a "change" variable may not be the same as the one for the related "state" variable (e.g. deforestation during a given period versus forest area at the end of the period). Precision on a "change" variable is always lower than that of the corresponding "state" variable and it may be illusory to aim at providing a reliable information on a change variable with the same spatial resolution as the related state variable. It is on the account of such considerations that FAO chose to estimate deforestation in the tropical world on a sampling basis as part of its Forest Resource Assessment 1990.
- More generally, there are variables which cannot be estimated now and for some years to come, on a georeferenced basis. For these variables, the good old concept of "reporting unit" used in forest inventory applies, i.e. the unit of reference (e.g. forest management unit, administrative unit) for which an estimate is provided for a given variable, with a confidence interval. For these variables the concept of average size of the reporting will replace that of spatial resolution.

3. *Third question: What are the possibilities to actually collect and organise this information?*

3.1 Introductory remarks

- Though it is good and challenging to be ambitious, it is also essential to remain realistic. It is true that hardly any segment of the international community, particularly after UNCED, will dispute the fact that assessing and making "systematic observations" of the world's forests is important. Yet, decision-makers have not so far earmarked the means, at both national and international levels, which would be, even to a small degree, commensurate with the size of the task. This is certainly the case in the Third World, as shown by the FAO's Forest Resource Assessment 1990 for the tropical and non-tropical developing countries. But it is also the case for most industrialised countries, with regard for instance to georeferencing and monitoring. The forestry community, and particularly those concerned with assessment and planning must strengthen their efforts, to raise the awareness of decision-makers at national and international levels on the crucial importance of forest inventory and convince them that money invested in these activities is well spent.
- Realism means also adopting a stepwise approach, at least in the first years, accepting that global assessments will not provide all the required information

and that priorities need to be set among the various kinds of data to be collected and organised, particularly between "essential" and "desirable" information. It means, as already stressed in section 2, that requirements must be critically reviewed and discussed with the users, and that cost-effectiveness and feasibility are key considerations. As also mentioned before, utmost care should be exercised to avoid superfluous information: history of forest inventory is full of data and reports hardly used, or not at all, for lack of consultation with the users and the undertaking of inventory for the sake of it.

3.2 *Two priorities*

- To a large extent global assessments build on assessments carried out at lower levels, and more particularly at national level, in a sort of "bottom up" approach. It results that, for better and more comprehensive global assessments efforts must be considerably reinforced in two domains at least.

  a) The first and overwhelming priority is that of development and strengthening of country capacity. FAO is particularly committed to these efforts within the framework of its forest resources assessment programme, with the support of trust funds from some donor countries (at present France, The Netherlands and Sweden). Its long international experience in this field has convinced it that country capacity building is a sine qua non condition of the improvement of global forest assessments.
  b) Another important priority is that of the harmonisation at international level of concepts and classifications. Use of information collected at national level for global assessments will be the more reliable if national institutions adopt, if not identical, at least compatible concepts and classifications. Here too FAO, and ECE-UN, have a long experience of "negotiations" of common terminology at regional and global levels, which they have pursued more recently in UNEP, IUFRO and other concerned organisations.

- However, and like in other fields of forestry (e.g. forest management), forest terminology which until ten years ago had remained the exclusive domain of foresters, has acquired a multidisciplinary, as well as a political dimension. Hence the need for international definitions to be "blessed" at intergovernmental level and the proposal made by the FAO Council to establish an intergovernmental panel of experts on forest assessment whose one duty would be to recommend definitions agreeable internationally. Such work should be closely articulated with that of the harmonisation of criteria and indicators at international level. The meeting contemplated in spring 1996, and referred to in section 2.2, may pave the way for the establishment of such a panel.

3.3 Joining efforts

- The costs of a comprehensive global assessment, meeting the essential requirements of most users are high and are not presently funded at an acceptable level. In addition to raising the awareness of decision-makers at national and international levels efforts are needed in two directions to alleviate the problem, i.e.:
  * develop synergies among those national and international institutions with a forestry mandate which are most active in regional and global assessments;
  * enlist more actively the support of those users of global forest information which are not part of the forestry community.

4. *Fourth question: What are your visions for how the global assessment should be conducted? How should the data be collected, who should do it, and how should the data be made available?*

4.1. Introductory remarks

The title of the Panel session mentions global forest assessments (plural) whereas this last question speaks of "the" global assessment (singular). Despite the seemingly unavoidable proliferation of unrelated initiatives world-wide, we prefer the latter formulation as it implies their indispensable harmonisation and convergence and the welcome reduction of overlap and duplication when it remains so difficult to gather the needed funding.

- We live in a real world made of sovereign nations, each of them with their own forest policies, forest ownership structures, forest management systems and forest institutions. These nations are represented by their governments. Fortunately they have built up over the years an intergovernmental system through which they accept (i) to exchange information, (ii) to develop and agree on common standards, norms and codes of conduct, and (iii) from which they expect global syntheses and outlook studies to be carried out in a neutral, unbiased manner, devoid of vested interests. Obviously this intergovernmental system, which is, for most of it, part of the United Nations, have a central role to play in the formulation and implementation of the global forest assessment.
- Within this intergovernmental system, and as a follow-up to the third session of the Commission on Sustainable Development (CSD - April 1995), an open-ended intergovernmental panel on forests has been established which is to review, inter alia, the whole issue of global forest assessment and make recommendations to the fifth session of the CSD.

- Global assessments are built for their most part, from information collected at lower levels, particularly by national institutions responsible in their respective countries for forest inventory and monitoring. This "bottom-up" approach can only be successful if these institutions are interested and encouraged to provide the type of information required for the global assessments; and if they know it will be used by entities which offer a guarantee of objectivity and political neutrality.

4.2 General mechanism

The intergovernmental organisations concerned of the UN system - basically FAO with ECE(UN) and UNEP - will continue to fulfil their mandate in global forest assessments. They should serve in a pivotal role, carrying out the core work concerned with the basic information (particularly areas and their changes over time), in full co-operation with the networks co-ordinated by subregional lead centres. Synergy at global and ecoregional levels should be secured with governmental and non-governmental organisations active in this field at it is already the case with the Joint Research Centre of the European Community, IUFRO and the World Conservation Monitoring Centre, either to strengthen the core work or to carry out specific studies on physical or socio-economic fields (e.g. detailed estimates of biomass, assessment of indicators of biological diversity, of land degradation and of socio-economic functions of forests). As already stressed repeatedly synergy and co-ordination are a must given the increasing size of the task and the limited funds available to implement it.

GLOBÀL FOREST RESOURCES ASSESSMENTS BEYOND 2001

SUMMARY OF THE PANEL SESSION

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The panel discussion was attended by over 70 participants. G. Lund welcomed the panelists and participants and gave an excellent overview of the need and scope of the future global forest assessment. He cautioned that even in a developed country like the United States it normally takes about 10 years to incorporate new parameters into the forest resources inventory cycles. Thus, parameters for the future forest assessments should be carefully defined in order not to put inappropriate burden on the inventory experts in designing an operational forest resources inventory programme within countries.

Four panelists gave presentations on their visions of the future global forest assessment. The papers submitted by Mr. J.P. Lanly, A.B. Temu, and B. Sarbini are included in the proceedings. The result of discussions is summarised below.

The scope of the future global forest assessment

There was a remarkable consensus among the participants that the global forest assessment should provide relevant information on the distribution and condition of all forests. It should be able to address issues related to forest conservation, management and development and also answer scientific questions such as those dealing with biodiversity loss, surface climate interactions, impact of deforestation and vegetation modelling etc. It should have built-in flexibility in scale and resolution and must provide information which is geographically referenced. One of the panelists thought that not only knowledge of spatial and temporal distribution of resources was adequate; the rules and regulations governing resource endowment were equally important.

Forestry information needs for better policies and decisions

Forestry information is needed for better policies and decisions at all levels i.e. local (forest management), regional, continental and global. However, forests are threatened at the local levels not at the global level. There is no such thing as 'Global Forest Policy' but information is needed by the scientific community and international decision makers to assess how the current situation develops scenarios for the future. The information is needed on variables such as those related to climate change, loss of biodiversity, ownership, protection status, forest plantations and management status. The parameters for forest assessment should be closely linked to the development of indicators of sustainable forest management. There is also a need to recognise the variability among different definitions and classifications systems.

It was recognised that the global forest assessment could provide only a synthesis and comparative analysis of the current situation at the global level and thus it has limited utility for forest management and planning at the country level.

Approaches to the future global forest assessment

There could be a variety of approaches to global forest assessment such as 1) aggregation of data and information from the local to global level, 2) appropriate sampling strategy, and 3) wall to wall global coverage. All of them have their strengths and weaknesses. Technology is another driving force for data collection, processing and integration. There are overriding reasons for country capacity building. However, adequate funding for carrying out a comprehensive assessment including all essential parameters is not available.

Business Meeting

Moderator: H. Gyde Lund, USA

GUIDELINES FOR WORLD FOREST MONITORING

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Abstract

IUFRO Working Party S4.02-05 has compiled International Guidelines for Forest Monitoring in order to promote standardized collection of selected data in such a way that the results may offer a common data base for research management. The goals of the guidelines, published by IUFRO secretariat in 1994, are to

- increase the opportunities to share plot information for research, inventory and remote sensing verification,
- assist researchers utilizing these data for modelling purposes, and
- support agencies aggregating data for global and regional forest assessments.

This is done by listing the definitions of the variables and the data to be collected and by presenting the principles of data collection suitable for international use.

The guidelines represent the input of several IUFRO 4.02 workshops and reviews by more than 100 voluntary specialists of forest inventory and remote sensing. However, the report should not be considered to be the final result of the process. It should rather still be regarded as a step towards improved information on forest resources, and it needs follow-up and further development in the future. These guidelines also show the potential role of IUFRO in contributing to national and international activities by providing a general framework for discussion and collaboration.

Key words: Global monitoring, harmonization, standardization

Introduction

The International Union of Forestry Research Organizations (IUFRO) celebrated its XIXth World Forestry Congress in Montreal, Canada, in 1990. During this Congress, it was proposed that Working Party 4.02.05, called 'Remote Sensing and World Forest Monitoring', should devote its efforts to global forest assessment by promoting the establishment of a permanent sample plot network.

As the first step towards a worldwide forest monitoring network, the international workshop 'REMOTE SENSING AND PERMANENT SAMPLE PLOT TECHNIQUES FOR WORLD FOREST MONITORING' was held in Thailand, January 1992. The main objectives of the workshop were to develop guidelines for establishing permanent sample plots and for forest monitoring. The work started in Thailand was further developed in Finland during the 'ILVESSALO-SYMPOSIUM', in August 1992. Altogether, more than 100 experts to date from all continents have participated in various workshops and commented different versions of the guidelines.

'Standardization of symbols in forest mensuration' is one example of earlier IUFRO guidelines (IUFRO 1965). This publication has successfully been utilized over three decades as a basis for a common language for foresters all over the world. IUFRO members have recently faced a more complicated problem, namely the standardization of the methods of forest resources monitoring all over the globe. The outcome of the process is now available as IUFRO World Series Volume 5.

Why guidelines?

Global forest resources are dwindling at an unprecedented rate in the tropics, and losing diversity and productivity in some other regions. The United Nations Food and Agriculture Organization collects information on global forest resources, the latest assessment of which is from 1990. The planning of the global forest assessment for the year 2000 is under way (Singh 1992). Several other organizations are making multicountry surveys and assessing the rates of change, including the United Nations Environment Programme, ECE Joint Research Centre, The Woods Hole Research Center, Smithsonian Institution, and others. Even more activities are being carried out at a country or sub-country levels by national and international agencies.

Many of these efforts are often uncoordinated and independent from one another. Many countries are not covered at all and, frequently, the collected data are not easily comparable, because different definitions and measurement methods may prevent the comparison of the results. For historical and economical reasons, forest inventory data has been concentrated on timber resources, and there is an evident shortage of non-timber information.

International organizations and cooperating nations should be working towards a common global monitoring goal to provide a complete picture of the status and trends of the world's forest resources. The international community of forest researchers is - through IUFRO - willing to promote forest monitoring efforts by offering a common scientific background for monitoring activities.

The purpose of the 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. They can offer:

- promotion of standardized or compatible collection and reporting of selected data or forest monitoring through cooperation in such a way that the results may offer a common data base for research and management;
- listing of data and definition of variables that should be collected to address emerging forest and environmental concerns;
- presentation of principles for collecting data that are suitable for international use;
- contribution to the establishment of a world forest resource information system;
- increased opportunities of sharing plot information for research, management, inventories and remote sensing verification;
- assistance for research scientists who collect forest resource information for modelling change and who conduct resource inventories and monitoring efforts;
- support for agencies that fund monitoring efforts and that have to aggregate data for global and regional forest assessment.

Contents of the guidelines

Information needs, use of remote sensing, permanent sample plots, existing monitoring information and infrastructure and data sharing are discussed in the guidelines.

Information needs assessment

The first step in any monitoring effort, global or local, is the information needs assessment (Lund 1986). The important questions in the very beginning are: *"for what purpose ?"* and *"who will use the results ?"*. If we know the techniques used for deriving the desired output, it is possible to decide the measurement needed in the field, and which other input data would be useful.

Local resource inventories, like conventional timber surveys, require detailed information on forest area and its location, timber volume by species and by log size classes, accessibility and ownership pattern (Husch 1971). In national forest inventories, the sustained yield of forest resources in the country is of primary concern. Forest area, and changes therein, as well as the balance between drain and growth estimates are factors that need to be highlighted. Changes in soils and forest health need to be investigated to ensure good resource utilization in the future.

Based on current global issues, the most important characteristics are the amount of forest cover, biomass production for carbon storage and sinks, rate of change of forest, and forest quality and health. Environmental quality includes ecosystem health, condition, and the biodiversity of the vegetation, and the vital connection between the vegetation and the rest of the ecosystem.

Different monitoring approaches require different information and, therefore, the acquisition of the data may vary from project to project. In order to guarantee the possibility of aggregating the data, a proposal on 'core information', will be made. The 'core information' should be collected in all monitoring projects. Standards and definitions for the most common variables are proposed in the guidelines.

Existing monitoring information

The existing data can be remotely sensed or field data, or even maps or other useful information. The more general the data sought, the more one may use remote sensing; while the more detailed data needed, the more one must rely on field sampling.

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 one km resolution. For local, sub-country purposes, the accuracy of aerial photographs may define the minimum areal changes to be detected. On a national scale, land satellites - like Landsat and SPOT - with resolution varying from 100 to 6000 square meters, may provide the basis for the follow-up of forest cover. On a regional scale, a convenient unit size is 1 km^2, which approximates NOAA-AVHRR/LAC pixel size. To create a connection between satellite data and ground conditions, field data are needed. If the goal is to follow-up the forest conditions, permanent field plots are recommended.

In many areas, existing information and permanent plot networks will be available. It is too often this information is not accessible to the scientific community. Therefore, the archiving and reporting of available data should be emphasized. An example of an index for Sahelian countries can be found in Prince et al. (1990). A list of international forest monitoring efforts has also been produced by Jaakkola (1992), and by O'Sauza et al. (1995).

A preliminary database on the existing permanent sample plot networks has been collected by an inquiry, and it will be updated by the UNEP. The objective of the permanent sample plot index is to provide additional data to that extracted from remote sensing, and to provide information for multinational research and modelling. The permanent plot database can be requested by e-mail, fax, telex or correspondent through the following address: Facility Manager, GRID-Nairobi, UNEP, P.O.Box 30552, Nairobi, Kenya. E-mail: EAINFO@unep.no

Currently the database is available on a diskette and it contains permanent plot information of 244 plot systems in 51 countries.

The need for new permanent sample plots

Monitoring can be carried out by using two basic methods:

1. Conducting inventories at different times using independent samples, and expressing the change as the difference in the results.
2. Using the sample locations at different times and deriving the change as a function of changes in sample units.

Permanent field sample plots are often the only reasonable way to conduct monitoring. The advantage of using permanent plots is that the sampling error is always in the same direction and thus does not disturb the change assessment.

The use of remote sensing provides new approaches to repeated observations at the same location. A pixel, or even a larger piece of a satellite image, can be regarded as a permanent plot. In the combined use of remote sensing and field plots, the remotely sensed data will often cover easily the area to be monitored. The remaining problem is then the statistical correlation between the accurate field observations and inaccurate remote sensing data.

In the field, permanent sample locations must be marked in such a way, that they will not be treated any differently from the environment. However, the markings should be clear enough, so that the measurements can be repeated after several years. In the areas where the forest is under high pressure, interference by local people in the study area has made remeasurement difficult (Watson and Nimmo 1992).

For monitoring global forest resources, a worldwide permanent field sample plot network is needed. The development of forest characteristics in detail may rely on field measurements, but the general condition of the forest can be followed up by remote sensing data. Common standards and definitions on is to how to measure and what to measure, and how to store the data, are needed in order to provide a sound basis for the establishment of the network.

What next?

The 'IUFRO international guidelines for forest monitoring' are not directly aimed at specific monitoring operations. The next phase would consequently be to directly support activities where the guidelines could be utilized. International cooperation would be needed at least in the following fields.

- establishment of an international field plot network for monitoring
- compiling a worldwide index or database of existing field plot networks
- compiling an information base on existing remote sensing data for forest monitoring purposes
- establishment of data sharing and information network on an international basis

The existing institutions and facilities should be utilized and strengthened in these tasks. However, some additional international cooperation and efforts by individual forest researchers will be needed.

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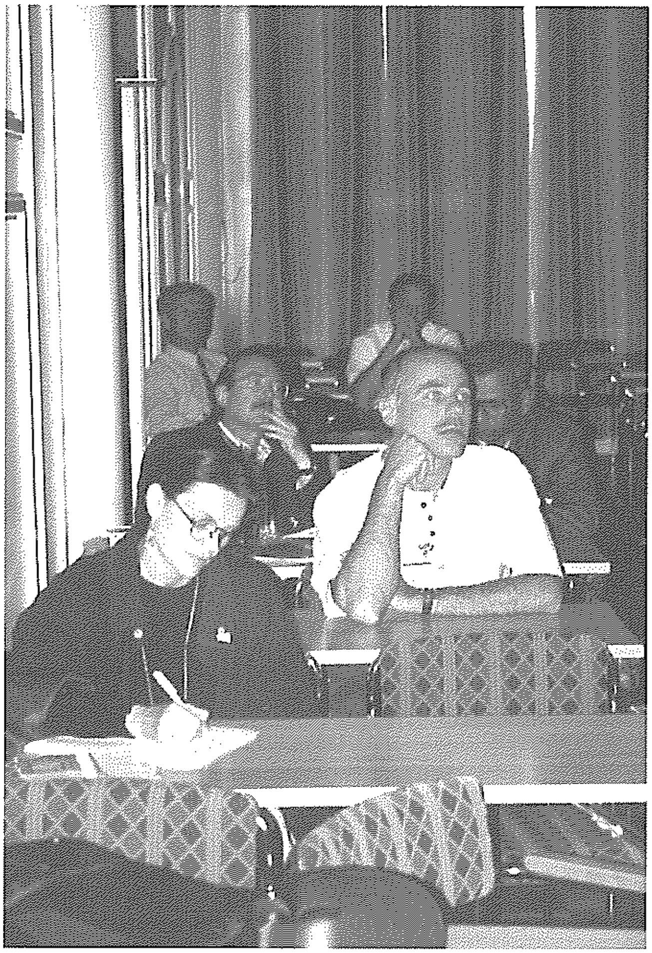
APPENDIX 1



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The IUFRO subject groups 4.02 'Forest Resource Inventory and Monitoring' and 4.12 'Remote Sensing Technology' held ten separate or joint meetings during the IUFRO XX World Congress in Tampere, Finland, in August 1996. A total of 42 papers were presented at these meetings. The papers are published in two volumes of proceedings, the one at hand and the other one published by the University of Joensuu.

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