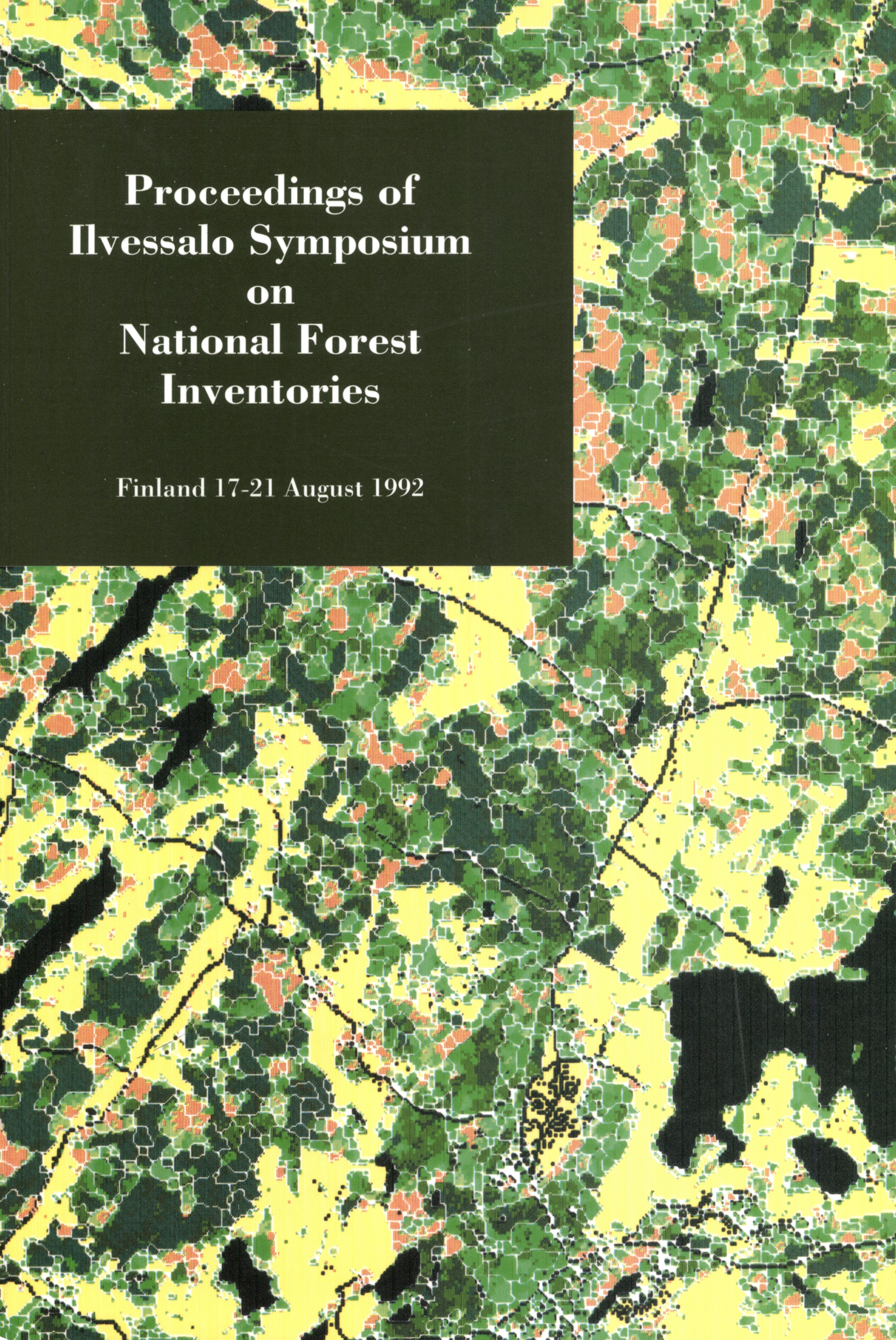
Proceedings of Ilvessalo Symposium on National Forest Inventories

Finland 17-21 August 1992



METSÄNTUTKIMUSLAITOKSEN TIEDONANTOJA 444
(The Finnish Forest Research Institute. Research Papers 444)

PROCEEDINGS OF ILVESSALO SYMPOSIUM ON NATIONAL FOREST INVENTORIES

Organized by

IUFRO S4.02

Finnish Forest Research Institute

Department of Forest Resource Management
University of Helsinki

Edited by
Aarne Nyyssönen, Simo Poso,
Johanna Rautala

Helsinki 1993

Available from: Finnish Forest Research Institute
Communication Unit/ Anne Ahti
Unioninkatu 40 A
00170 Helsinki
FINLAND

ISBN 951-40-1267-4
ISSN 0358-4283

Gummerus Kirjapaino Oy
Jyväskylä 1993

CONTENTS

Opening Sessions

National Forest Inventories

Global Monitoring of Forest Resources

Monitoring Forest Health

Tree and Stand Models in Forest Inventory

Sampling Designs with Special Emphasis on Remote Sensing

Moderators' Summaries on Different Sessions

PREFACE

Inventories to cover Finland's forests were begun in the early 1920s by Dr. Yrjö Ilvessalo, later Member of the Academy of Finland. He then conducted these inventories during the period of 40 years and made a remarkable contribution to IUFRO's activities. The symposium was organized to celebrate the Centenary of his birth and to discuss the progress made in the methodology of large scale inventories.

More than 80 experts on forest inventory and monitoring from 22 countries and all continents participated in the Symposium. Some 35 papers were presented in the following five sessions, held during the first two days at the University of Helsinki: National forest inventories, Global monitoring of forest resources, Monitoring forest health, Tree and stand models in forest inventory and Inventory designs with special emphasis on remote sensing.

The participants were then transferred to Savonlinna in Eastern Finland for two excursion days. Firstly, there were demonstrations of the methods used in the Finnish National Forest Inventory, growth and yield studies and the management planning of farm forests. The excursion on the second day took the participants across Finland's east boundary to Russia, where operations of a Finnish-Russian forestry enterprise and inherent forest inventories were demonstrated.

The final session took place in the city of Mikkeli on the fifth day while returning to Helsinki. The draft summaries of the moderators were discussed and agreed. In addition, information was given about some future events, including the IUFRO XX World Congress to be held in Tampere, Finland, August 1995.

A follow-up workshop of IUFRO S4.02.05 with about twenty participants was held on August 22 to further elaborate "Guidelines for Forest Monitoring".

The Organizing Committee was formed by Prof. Simo Poso (Chairman), Mrs. Anne Ahti (Secretary), the other members being Professors Kullervo Kuusela, Kari Mielikäinen, Aarne Nyyssönen, Risto Päivinen and Erkki Tomppo, and Mr. Sakari Salminen. The sponsors of the Symposium are mentioned in the opening statement by the chairman (see below).

The persons interested in receiving the Proceedings may contact Mrs. Anne Ahti, The Finnish Forest Research Institute, Unioninkatu 40 A, 00170 HELSINKI, Finland.

OPENING ADDRESS

Simo Poso
Professor of Forest Mensuration and Management
University of Helsinki

Ladies and Gentlemen

We are just starting the meeting "National Forest Inventories". Under this umbrella theme we will have five separate sessions representing fairly wide range of disciplines from forest inventory methodology to tree and stand models, forest health monitoring, remote sensing, and global forest assessments.

Forest inventory and monitoring is a key issue when managing our valuable renewable forest resources. No sensible forest policy is possible if the quantity and quality and the changes and trends of forests are not known. As experts and scientists of this strategic field we have a great responsibility not only at national but also at global level.

The aim of the organisers of this meeting has been to bring forest inventory experts and scientist from different parts of world together to change experiences and ideas and to promote co-operation in forest inventory and monitoring efforts. It seems to me that we have achieved these objectives very well. Here, we have experts from all continents and forest conditions.

The basic methodology of forest inventory and monitoring is international. However, we try to offer to you also local Finnish flavour in our subject matter.

Finland is a country of forests and forestry. Because of its very northern location Finland is, perhaps more than any other country, dependant on forest. Foreign trade is essential to Finland and about 50 % of the net income from foreign trade originates from forestry and forest industry products. This reflects our forestry as you will see during this week.

There are also other reasons to organise this meeting in Finland just this year. A prominent Finnish scientist in the field of forest inventory and forest growth studies, professor, academician Yrjö Ilvessalo was born hundred years ago, in the same year as IUFRO was founded. This is why we have named this meeting the "Ilvessalo-Symposium". Professor Aarne Nyyssönen will tell us more about Ilvessalo in a little while. Yrjö Ilvessalo died about nine years ago but we are honoured that his sons, Doctor of Forestry Mikko Ilvessalo and Doctor of Political Sciences Jaakko Ilvessalo and their wives are here with us now.

This year is also national jubilee year for Finland. Seventy five years ago we won our independence as a state. A good way to celebrate this is to promote international co-operation, and in our case, what would be a better field to do it than forestry.

The initiative for this meeting was made by Prof. Pekka Kilkki. He sent a letter to Gyde Lund, the leader of our Subject group in January 1990 for IUFRO sponsorship. At that time, Kilkki was in charge of forest inventory and monitoring in the Finish Forest Research Institute, as was Yrjö Ilvessalo earlier. Then, a tragedy struck. Pekka Kilkki got to a fatal illness and died almost two years ago. We other organisers felt that it was our duty to complete his initiative as well as possible.

When reading the summaries of symposium papers it became clear to me that there are great differences in the conditions and problems of our subject matter between different parts of the world. The Nordic countries form one group with their long traditions with sample-based, national forest inventories. Switzerland has a very well controlled system based on permanent sample plots and GIS. The areas in the USA, Canada and Russia are so extensive that the inventory problems are somewhat similar to global inventory. Most difficult problems, however, exist in the developing countries. Sustained use of the natural resources is endangered in the tropics whereas forest area and growing stock have been increased in the developed temperate-zone countries. Everywhere, inventorying changes in land use and forests and environmental conditions is becoming more and more important.

Almost one hundred persons have registered in the symposium. Some, however, will take part only in the Helsinki program.

With this number of participants we have good possibilities to get to know each other much better than is possible in big conferences and, I hope, it will be rewarding for all of us both individually and professionally.

As a Chairman of the Organising Committee I want to express warm thanks to all persons and organisations who have made this meeting possible. Financial aid we have received from Ministry of Agriculture and Forestry and the Academy of Finland. The participation of some people from remote regions has become possible through the financial aid from Finnish International Development Agency, FINNIDA, and USDA Forest Service, Tropical Forestry Program. Central Co-operative Bank of Finland (Osuuspankkien Keskuspankki Oy) has presented you the briefcases. We have also got assistance from IUFRO Subject Group "Forest Inventory and Monitoring" and Working Party "Remote Sensing and World Forest Monitoring", Forest Research Institute of Finland, the Universities of Helsinki and Joensuu, the Central Association of Forest Industry (Metsäteollisuuden Keskusliitto) and Forest Company Enso-Gutzeit Ltd in arrangement of the excursion to Russian Karelia with the co-operation of their Russian partners.

The most important prerequisite for a successful meeting, however, are you, the participants of the symposium. I want to assure you that we have tried and will try to make this meeting fruitful and enjoyable to you. I hope that this meeting helps us to find right questions which should be answered by forest inventories and right methods to collect the necessary data in different ecological, socio-economical and political conditions.

I wish you warmly welcome to make a good symposium!

YRJÖ ILVESSALO'S LIFE WORK

Aarne Nyyssönen
Professor Emeritus
University of Helsinki

We have come here to discuss topical problems of large-scale forest inventories, but I'd like to start by remembering Professor Yrjö Ilvessalo, the man to whom this Symposium is dedicated, the man who conducted Finland's national forest inventories for 40 years. It is my priviledge to present him to you with a brief review of his life work.

Yrjö Ilvessalo was born on the first of December, 1892, and died at the age of 91 in 1983. So we're taking an early start in celebrating the centenary of his birth, but the organizers thought you might prefer going on excursion in Finland at this time of year rather than in December.

Ilvessalo graduated at the University of Helsinki in May 1914, and began working for the National Board of Forestry only four days later. He began with various assignments under the venerable title of "forest conductor." He received his master of science degree in 1917, and his licentiate and doctoral theses were published in 1920. After teaching forest mensuration at the University of Helsinki, he became a professor of forest mensuration and inventory at the Finnish Forest Research Institute in 1922. In 1948 he was named a member of the newly established Academy of Finland, but he continued working at the Forest Research Institute till his retirement in 1962. He also wrote a number of papers in later years.

It's been said that the principal object of Ilvessalo's research was Finland's forest resources. We can accept this broad definition if we include research on growth and yield in it.

In 1909 an older Finnish scientist, A.K. Cajander, had introduced an original theory of forest types, i.e. the assessment of site quality basing mainly on ground vegetation. But this theory was not given a numerical expression that would enable the classification to be used in research and practice. Cajander himself argued the need to make yield tables based on forest types. It became Ilvessalo's task to study the importance of forest types from the point of view of forest mensuration, supplemented by yield tables.

Yrjö Ilvessalo studied fully stocked, unthinned stands basing on an abundant material. In his doctoral thesis of 1920 he drew the conclusion that forest site types were well suited for the classification of site quality. He then prepared yield tables for even-aged, pure stands of the three main tree species in the southern half of Finland. The structure and development of growing stock are indicated in the tables by different characteristic variables. Growth and self-thinning are also included. Ilvessalo's tables have had great practical utility owing to their ease of use and because of the lack of research on the development of managed forests up to the '50s.

In the '30s, Ilvessalo prepared yield tables for normal stands in southern Lapland. This project, in which pine, birch and old spruce stands were studied extensively, showed that pine grows the best in that area. After his retirement, Ilvessalo made growth and yield studies in other regions of the north and finally, in collaboration with his son, he published a comparative study on the yield of forest types in different parts of Finland.

Systematic study of stands treated with different kinds of thinnings was started by the Forest Research Institute in 1924, when the establishment of a large number of permanent sample plots was begun, mainly in the Institute's experimental forests. Since then, measurements have been continued and thinnings applied to these plots at regular intervals. Ilvessalo directed these operations and prescribed the methods to be applied in the work. A lot of analysis still remains to be done on the material collected.

A long-felt need for reliable information on forest resources, increment and utilization, due to the importance of wood-based industries for the Nordic countries, led early in this century to the planning of large-scale inventories. In Finland, the ground work for a pilot inventory in two local-authority areas was done in 1912; the research was completed by Ilvessalo.

Investigations commissioned by a Tax Reform Committee were made in 1921. These included a survey line in the southern half of the country. It was soon decided to extend the inventory in the whole country. A detailed proposal for the actual plan was elaborated by Ilvessalo, and the National Forest Inventory was carried out by the Forest Research Institute under his direction. In addition to this First Inventory (1921–24), Ilvessalo also conducted the Second and Third Inventories (1936–38 and 1951–53), and the first part of the Fourth Inventory (1960–61).

The essential features of the inventories have remained unchanged, though methods of estimating silvicultural conditions and management needs of forests were developed continuously. In every case the survey was made in the field, using survey lines in the southwest-northeast direction, with a basic distance between them of 13 kilometres. Air photographs were used experimentally in the Third Inventory in areas in which field work would have been difficult and which had a limited economic importance. In surveying along a line, ocular estimation of every stand was made to record the site, growing stock, its condition, etc. One purpose of using sample plots measured at regular intervals – usually one kilometre – was to form bases for correction of the ocular estimations; another was to permit calculation of additional information – like distribution of the growing stock and its increment into diameter classes, the quality and quantity of saw-timber trees, etc. Punch-cards were used in processing data in the Second Inventory. A method proposed by Lindeberg (1924) was used for calculating the precision of the results: to eliminate systematic error, the results from two adjacent strips are continuously compared with each other. The differences thus obtained are the factors in the formula for the standard error.

Ilvessalo presented the inventory results mainly as publications of the Forest Research Institute. Results have also been published for regions, various combinations of regions, and for the southern and northern halves of the country separately. Results on physical and biological features in Finland were also presented in map form.

Dr. Pohtila will be speaking on the importance of the National Forest Inventories, which will be discussed in larger detail later during this Symposium.

The abundant material collected in the inventories gave Ilvessalo a chance to research problems like climatic variations of tree growth and determination of the desirable cut. In the intervals between the inventories he devoted himself to other research problems, the material for which was obtained partly from the inventories and partly by special surveys and data compilation. Growth and yield studies have already been dealt with. Another large work was the compilation of Tree Volume Tables based on 12,000 sample trees, published in 1947. These tables give the unit volume, including bark, for each tree species when diameter at breast height, the height, and taper are known. By taper is meant the difference between D.B.H. and the diameter at 6 metres of trees at least 8 metres high. The volume excluding bark can be obtained from that including bark by using percentage figures based on the previously mentioned factors, or if necessary, by measuring the thickness of the bark at breast height.

Apart from his research Ilvessalo had a long career as a teacher. He lectured to forestry students at the University of Helsinki for twenty years, and to future land surveyors at the Helsinki University of Technology for 26 years. As a lecturer, he contributed to the success of many courses. An important aspect of his tutorial work was his personal guidance of post-graduate students; he also managed research opportunities for his coworkers and students with great skill.

Ilvessalo was an exceptionally productive scientist. The total number of pages of his research papers is almost 4000. He also contributed to textbooks, periodicals and newspapers, and gave lectures. He deserves special praise for his presentation of results in popular form for general comprehension. He frequently drew conclusions to explain new problems of current interest.

The same desire to serve practical ends prompted him to join many committees preparing forestry reforms. In the late '50s, an important plan was worked out under his direction for the development of forestry research in Finland.

The portrait of Yrjö Ilvessalo as a scientist would be incomplete without mention of his extensive work in various scientific societies, organizations and boards as a member or chairman. His interest in developments in other countries led him to go on study tours at an early stage of his career. Later he was closely involved in international activities. He represented Finland at numerous conferences and other meetings. The great honours bestowed upon Ilvessalo attest to the quality of his work. For instance, he was granted an honorary doctorship by three foreign universities.

And finally, special mention is due to Ilvessalo's work in IUFRO. He took part in all eight congresses between 1929 and 1967, and gave several papers at them. He was a member of the International Council at five congresses as a representative of Finnish research organizations. In the '30s he was also a member of the Executive Board. Further, from 1948 to '56 he headed the Research Section "Growth and yield, and forest management," which corresponded to the present Division 4. His great interest in IUFRO is demonstrated by the fact that his last paper was a detailed report on IUFRO Congresses, dictated into a magnetophone after his eyesight had weakened.

IMPORTANCE OF NATIONAL FOREST INVENTORIES IN FORESTRY RESEARCH AND PRACTICE
Keynote Address

Eljas Pohtila
Director General
The Finnish Forest Research Institute

The words "national forest inventory" carry a special ring to them not only here in Finland but in the other Nordic countries as well. For us Finns, they bring to mind pictures of endless forests and of men laden with instruments roaming through them, tenaciously "walking the line" – from one side of the country to the other. The recollection would not be complete without the figure of Yrjö Ilvessalo – at times in his field attire and at other times in his academic finery, but always just as wise – leading the work. I do believe that here is a picture that has rightfully earned its place among our other national symbols of lastin character.

For us foresters, to cast our minds back to the time of the first national forest inventories means a spiritual return to a time on innocence, a time that knew nothing of today's bitter disputes over how forests should be managed. In the background there is the recent recognition of Finland's independence in 1917 and the associated trust in a better future and a shared concept of the important role that forests would have in the young nation's economy. It is interesting to note here that recollections of these early years of national forest inventories by foresters have also risen to great literary heights. In his novel "Seitsemän tuntia erämaata" (Seven hours of wilderness), Professor Valter Keltikangas gives us a moving depiction of what has been referred to as the "long line" of the second national forest inventory – this book continues to be a favourite work among Finnish readers.

Without disputing the possibility of romantic subject matter being involved as well, it is necessary to point out that the reasons at the back of the initiation of national forest inventories were essentially very prosaic by nature. Forest policy in Finland, as in the other Nordic countries, had been dominated by an age-old fear of the depletion of our forest resources. The consumption of timber for energy and other household purposes was great and industrial usage was increasing rapidly. The slash-and-burn era had only recently ended – you might say that the last of the cleared blocks of land were still smoking. And then there was the need for a reliable basis for taxing forest income and forest property.

It's also true that Finland's forest resources had been estimated before Ilvessalo. These estimates were, however, very rough-and-ready and based mostly on hearsay. The first national forest inventory implemented under the leadership of Ilvessalo brought about a total change of character for forest resource data. It was put into an exact, operational format and thus its reliability could also be evaluated by the application of statistical methods.

The first national forest inventory fully met the forest policy goals set down for it. Fears concerning the fate of Finland's forests were quickly dispelled and forest taxation was provided with a basis that turned out to be so solid that it has lasted right up to the present. It is only now (and still with some hesitation) that we Finns are entering into a period of transition in changing over from area-based taxation to taxation based on income from sales of timber.

Once the results of the inventory were published, it was time for a radical review of forest management practices. To date, the forests of Finland (and of the other Nordic countries too) had been treated primarily with light selection fellings; attempts had been made to modify them in the direction of sustained saw-timber selection in accordance with the teachings of selection system forest management. The results produced by the inventory indicated that methods of this kind were out of place in our boreal forests. The inventory teams came across extensive areas that had been "left halfway" and "spoiled". The all-agedness that would enable continued selection cuttings to be conducted could be achieved only at the cost of wide openings in the canopy and underproductiveness.

Sustained yield management required a shift over to standspecific forest management with individual stands being the treatment units instead of single trees or groups of trees and in which the aim is to raise the trees forming a stand evenaged and to regenerate them at the one time. The forest site type theory presented in 1909 by Cajander, the truly grand old man of Finnish forest researchers, had already blazed the path for the new system. The decisive contribution to moving over to stand-specific forest management was made by Yrjö Ilvessalo when he formulated growth and yield tables for the forest site types defined by Cajander. With these now available, it was possible to calculate the allowable cut for all of Finland's forests. The new approach received official recognition by way of the new private Forestry Act that came into force in 1928 – the new act prohibited selection cuttings. Though often criticised, the policy adopted then has stood the test of time so far.

The results of the inventory also opened our eyes to utilisation potentials still unexploited. It was natural to go on and draw up silvicultural programmes aimed at rectifying shortcomings. Forest improvement legislation was soon passed enabling private woodlot owners to apply for government funds for improving the state of private forest estates.

The 1960s and 1970s were the golden decades of forest policy aimed at increasing the efficacy of timber production. These were the times when several consecutive semi-official forestry financing programmes were formulated with the data obtained from national forest inventories forming the basis. We were not totally successful in their implementation, but thanks to these programmes Finland's standing forest resource and the growth of this resource is greater than ever before.

In the old days, there was a lot of concern expressed over the danger of our forests being depleted (to the extent that the founding of new wood industry plants required a licence). Nowadays, there is concern over overproduction – even of timber. The most recent of our official forestry programmes – "Metsä 2000" (Forest 2000) – places emphasis on the need for increasing the consumption of timber raw material. Without it Finland's forests will begin to degenerate and the investments made will come under threat.

The fear for Finland's forests is not a thing of the past, however; it has simply taken on a different form. It is feared now that we shall lose our forests because of air pollution and other man-made changes in our environment. There is also the fear that we shall run out of virgin forests. During the recent years, we have witnessed a situation in which forest uses other than timber production have received unforeseen emphasis and political support. Changes in attitude have been speeded up by court disputes between practitioners of traditional forestry and environmental activists. The setting is somewhat similar the world over. The forests of Finnish Lapland have been compared to the rain forests of Brazil – in both cases the practicing of forestry has been claimed to lead to irreplaceable loss of biological diversity.

The trustworhiness of the results of national forest inventories has been put to test in these disputes – but they have withstood it. The results of a total of eight consecutive inventories constitute such an impressive chain of proof on forest development and of the influence of forest management measures on this development that even the best of demagogues will not be able to discredit them. My personal belief is that the success story that forestry in Finland represents would not have been possible without the solid knowledge base brought about by the national forest inventories conducted in this country. National forest inventories constitute an apparatus of central significance for the practicing of Finland's forest policy. The information provided by the inventories have made it possible for us to relate to one another timber production measures, timber consumption and even including the establishing of industrial plants. Without the frame of reference created by the inventories it is very unlikely that we would have dared to proceed with the radical regeneration of our old forests.

In many places these regeneration cuttings exceeded the current growth in the region and attracted a lot of attention and opposition too. And yet these operations were necessary for the revival of timber production capacity in the areas concerned.

Over the decades, the inventories conducted have taught researchers and practising foresters to speak the same language – this has been essential from the point of view of the implementation of the numerous forestry programmes. National forest inventories have been examples that various forestry organisations have followed in their own spheres of activity and the national results have provided control and calibration data for the organisations' own applications. The adoption of Geographic Information Systen (GIS) applications have made the sample plot data collected from the nations forests useful as such to the planning personnel at the regional level. And vice versa – the national forest inventory material can be accessed for computing allowable cuts and for drawing up management plans for any particular woodlot if so desired. The planning software based on simulation and linear programming and developed in conjunction with the inventories has also been made use of in practical forestry.

While the emphasis in national forest inventories in Finland continues to be in timber resource data, we shall need to pay increasing attention to parameters depicting the ecological state of our forests. The third national forest inventory of 1951–1953 included some very thorough charting of fauna and flora – today, threatened as we are by environmental changes, the worth of this control data is immeasurable. Finnish Lapland's reindeer pastures were inventoried in conjunction with the sixth national forest inventory; this in turn extended the inventory's goals in the direction of satisfying multiple use information requirements. Most recently we have included defoliation of trees and overall monitoring of the state of health of forests within the range of data collected in inventories. There is a major political demand for this information just now.

It is quite apparent that national forest inventories are developing into a kind of overall forest research programme for Finland within which the purpose is to ensure the representativeness of various forest-related observations and to proportion the phenomena to one another and to the nation's forests as a whole. At least this is how we at the Forest Research Institute see the matter – at the institution that has shouldered the responsibility for the national forest inventories right from the start.

This has been an assessment of Finland's national forest inventories mainly from the point of view that the inventories are an example of service research that meets the needs of political decision making and practical forestry. This is a onesided approach and it fails to do justice to the fact that one is dealing with a distinct branch of science which, like all other branches of science, has an intrinsic value and motivation of its own. The planning work involved and the implementation of inventories as such constitute a demanding research undertaking. Development of methodology and the application of new technology have offered and continue to offer challenges to researchers. Models depicting forests, variation in forest growth, forest regeneration, measurement of trees, site classification, photogrammetry, biometrics etc., are all topics that are closely allied to national forest inventories. The research work connected to forest inventories falls within the sphere of exact sciences and it is very probable that this research has had a fruitful influence on the other forest sciences whose traditions may be closer to what may be referred to as sympathetic liberal arts.

Distinguished participants!

National forest inventories have proven to be a useful means of approach in Finland when dealing with a wide range of forest-related problems. Perhaps this practice has something to offer when dealing with global forestry issues? I know that you will be discussing matters of this kind during this symposium. I also know that this symposium has been well organised and I am sure that you will be successful in what you have come to do here. I wish you all the best in your undertaking.

NATIONAL FOREST INVENTORIES

SAMPLING DESIGNS FOR NATIONAL FOREST INVENTORIES

H. Gyde Lund
Leader, IUFRO S 4.02.00
Forest Resource Inventory and Monitoring
U.S.D.A. Forest Service, FIERR
Washington, DC, USA

ABSTRACT

National forest inventories are data collection efforts designed to report on the extent, state, and condition of the forest resources of a given country. Few national inventories result from a single sample. Most are aggregations of several different efforts. There are some nationwide estimates of forest cover resulting from wall-to-wall, aerial photography or satellite-based remote sensing especially in the tropics. The methods and roles of inventories have changed over time and will continue to do so in the future. Our information needs are increasing to the point that we now need to be designing holistic, multiple resource inventories. These inventories must also meet global needs as well as national and local needs.

Keywords: Inventory, global monitoring, remote sensing

INTRODUCTION

Hyvää huomenta! National forests are areas, defined by either vegetative cover, land use, or both, that occur within the territorial boundaries of a given country. National forest inventories are data collection efforts designed to report on a country's extent, state, and condition of the forest land and resources. Decision-makers use such estimates to develop land use policies for the nation. Periodic national assessments provide trend information which further influence land management policies and decisions. International organizations, such as FAO, combine national inventories with information from countries to provide regional and global assessments. These in turn influence international policies, trade agreements, and are often the basis for research on global environmental and social trends.

In 1978, the International Union of Forestry Resource Organization (IUFRO) held an international conference on National Forest Inventories in Bucharest, Romania (Cunia 1978a and b) that reported on national forest inventories in countries throughout the world. Pelz (1991) summarized the current European forest inventories at the IUFRO Symposium in Birmensdorf in 1990. Now we are meeting once again to discuss national forest inventories. The goal is to celebrate the centenary of the birth of Dr. Yrjö Ilvessalo and to discuss the progress in the methodology of national and other large scale inventories. This paper summaries a history of forest inventory and examines some of the underlying principles behind current designs. Lastly, it outlines some thoughts about where we should be heading in the future.

HISTORY

People have been making estimates of the extent of forest resources since they first started staying in one place and staking out territorial claims to the land. Information sought was if the lands could supply the needed game, fuel, and building material. Scouts gathered information as they saw it reported the information verbally to their leader.

Over time, individuals and clans combined their lands into kingdoms and then nations through conquests or mutual agreements. When settlements first started, the forests were obstacles to over come. Later, as villages and cities grew the demand for fuelwood and sawtimber increased. Forests began to take on a value in themselves. Early timber cruisers used visual estimates, calibrated by occasional felling of sample trees to determine volumes on tracts of land (Loetsch and Haller 1964). Because of the vastness of the timber resource, people thought forests to be limitless. Exploitation and extensive clear cutting were common in many areas of the world and still are in the tropics.

In the temperate areas, with no new lands to acquire, people began to realize there was a limit to the forest resources. National movements started to set aside lands for the production of timber on a permanent basis. The conservation movement started in Europe in the early 1800's. By 1870, it had spread to North America and other parts of the world. The turning between exploitation and conservation in France, for example, came around 1824 with the creation of the Ecole Nationale des Eaux et Forets (Gadant 1991). In the United States, this movement gained momentum in 1872 with the setting up of National Parks and in 1891 with the creating of National Forest Preserves.

In the 1890's, foresters determined increment by the comparison of two periodic inventories plus records of removal volume in Switzerland and France (Gurnaud 1897). This early work gave rise to continuous forest inventories (CFI) which are very popular today. Foresters often employed strip cruises at this time. While foresters were using sampling, mathematical statistics to permit the calculation of the reliability of the inventories were not available. Information sought included volume and increment.

Norway started a national inventory in 1919 and by the 1920's, all Nordic countries had some type of national effort going. The early work of Dr. Yrjö Ilvessalo in 1924 is heralded as one of the first statistically-based, national forest inventories (Tomppo and Siitonen 1991). In addition to being able to calculate the reliability of the surveys, inventory planners could, for the first time, use statistics to design data collection efforts to achieve predetermined allowable sampling errors. This gave the best possible relations between permitted expenditures and required precision. Thus, foresters could use mathematical sampling techniques instead of costly enumeration and subjective visual or representative sampling. The world owes so much to Dr. Ilvessalo, and it is fitting that we dedicate this symposium to him.

Since that the work of Dr. Ilvessalo, many countries have launched statistically-designed national inventories. The United States, for example, launched its first statistically-designed inventories to provide state and national statistics in 1930 (Lund 1984).

World War II brought many forest inventories to a halt. Following the War, CFI and permanently-established, systematically-located, fixed-area plots became a standard for large area surveys in many parts of the world (Stott 1968). Foresters, who served as photo interpreters in the War, began to use aerial photography to aid in forest inventories. They developed identification keys and various bits of gadgetry to classify and measure vegetation from air photos. Volume tables, developed through regression techniques, used measurements of crown diameter, canopy coverage and heights extracted from aerial photography. These new developments provided additional tools by which the inventory specialist could use to reduce field costs.

In 1946, the first electronic digital computer was developed. By 1950, automated data processing (ADP) gained popularity in the inventory field. Users found the computer enabled them to process information faster and with less error. It also permitted foresters to carry out previously complicated and cumbersome calculations. This capability lead to the development and use of more statistically-complex, but efficient sample designs. These designs include stratified sampling, sampling with partial replacement, and 3P (probability proportional to prediction) sampling. Also during this period, variable radius plots came into vogue for effectively gathering estimates of timber volume.

In 1970, the utility of space imagery for resource inventories made its debut. Foresters used Apollo 9 imagery to survey 4.9 million ha of forest land in the Southeastern United States (Langley 1975). Since that time, researchers have used imagery from satellites such as SPOT, Landsat, and NOAA's Advanced Very High Resolution Radiometer (AVHRR) to provide routine estimates of forest cover.

Until the early to mid-1970's, the emphasis of most national forest inventories was to get estimates of timber growing stock and trends. Since that time, however, there has been an increase in the interest of other forest products and the environmental, economic,and social roles that forest play locally, nationally, and globally. I discuss the impact of these new needs later in this paper.

APPROACHES TO NATIONAL FOREST INVENTORIES

There are two basic approaches for carrying out a national inventory. One is the single data collection effort where one designs one sampling method and has one group formed specifically to provide statistics for a country. The other method is by aggregation of existing inventories which may be of different designs and conducted by different organizations.

Single Effort

Through the single effort, data are collected by one group, using the same design across the entire country. Nation-wide inventories conducted in one single effort are common in the Nordic countries and in relatively small countries such as Austria, Belgium, Morocco, Nepal (Sharma 1992),Solomon Islands (Fearnside and Hibberd 1992), Switzerland (Köhl 1992), Taiwan, Vanuatu (Baldwin et al 1992), and Vietnam (Chat and Mon 1992). Lately, the single effort has become very popular where researchers use satellite-imagery to map the forest cover across a nation or groups of nations.

There are essentially two kinds of designs used for single-effort national inventories - those that rely primarily sampling without stratification and those that use remote sensing as a base for stratification and allocation of samples. A refinement of the latter are inventories that use wall-to-wall mapping as both a product and a basis for sampling.The methods discussed in this section may also be options for the sub-national inventories mentioned above.

Sampling without stratification

These inventories are either random, systematic, or systematic with a random start. Purely random samples are seldom, if ever, used in nation-wide inventories. One is never assured of sampling the population of interest. Systematic samples distributed across the inventory unit, were common before the use of aerial photography and satellite imagery. These included strip cruises and line transects. Such techniques are still being used in several European countries including Belgium, Germany, Italy, Austria, Switzerland, and Sweden (Lecomte and Rondeux 1992). However, inventories that employ remote sensing for stratified sampling are becoming more common.

Sampling with stratification

Stratification is the process of dividing an inventory unit into relatively homogeneous areas based on what foresters can interpret from imagery or maps. If stratification is done before sample selection (pre-stratification), it will reduce the number of field plots that the survey crews need without stratification. If stratification is done after sample selection and establishment (post-stratification), it will reduce the sampling error compared to the sampling error without stratification. There is little argument about using stratification to improve the efficiency or reliability of an inventory. The question is whether to use pre- or post-stratification.

Pre-stratification requires that foresters form strata before sample selection. Thus the inventory specialist must develop some type of classification and often mapping system in the early stages of the inventory. Use pre-stratification in the following instances:

a. If the classes or strata show extreme differences, such as croplands versus forest land, and for which the decision-maker needs information.
b. If the classes, strata, or mapped polygons are fairly large so distinction between the classes both on the ground and imagery is relatively easy (that is the strata are not intermixed giving a mottled appearance).
c. If the field sampling or data collection process in several of the strata are considerably different from what crews would collect in other strata. For example, vegetation data collected on crop lands intuitively is different from that collected on forest lands.
d. If the decision-maker has clearly set inventory goals and the inventory specialist does not expect the reshuffling of field plot information across strata.
e. If the decision-maker needs data for every strata.
f. If some areas are remote and inaccessible where the cost of field measurements would be high. In this instance, one could use a lower sampling intensity than in areas that are more accessible.

When using pre-stratification, one has the choice of proportional allocation versus optimum allocation for the distribution of field plots. With proportional allocation, the strata having the largest area will receive the most plots and the stratum having the smallest are will receive the least. The advantage of proportional allocation is that the field plots have nearly the same weight. The impact of errors or changes in classifications will not be so large as through optimum allocation.

Under optimum allocation, the inventory specialist assigns most field plots to the stratum with the highest expected variances. Thus strata that are relatively small in area, but very heterogenous internally, could require the most plots. Here, errors or changes in the classification of field plots could have very large impacts on the results of the inventory. On the positive side, optimum allocation will result in the least amount of field plots for a given cost.

Inventory specialists often use post-stratification following a systematic sample of some sorts.

a. If mapping or imagery is not available in time for the inventory.
b. If the mapping is so interspersed that developing a stratified sampling frame is cumbersome to impossible.
c. If the classes, strata, or questions a decision-maker may ask are apt to change in the live of the inventory.
d. If it is not so important to have data on specific classes of land as it is to have data on all lands.

Inventory specialists also use systematic sampling with post-stratification for long-term monitoring. Boundaries of vegetation types can change over time. This can raise havoc with plot weights if pre-stratification and especially if the inventory specialist used optimum allocation were used. A systematic sample with post-stratification will also yield a sampling of strata proportional to size.

A disadvantage of the systematic sample with post-stratification, is the chance that a certain stratum may not be sampled. This often occurs when there are very small stratum or when the distribution of the polygons are such as they fall between the systematic sample.

In summary, pre-stratification is more efficient for a set of specific goals. If the inventory goals become moving targets as they are now in many parts of the world, a systematic sample of permanent plots with post-stratification may be the best bet over the long term.

Mapping-based inventories

Mapping-based inventories rely on remote sensing (aerial photography or satellite-based imagery) to produce type maps or maps of forest cover. At a minimum, image interpreters use ground truth to help with the development of the maps. In this case, the primary product of the inventory is the type map and estimates of forest area. More sophisticated designs use the mapping in a post-stratification of randomly-selected field plots yielding both maps and the more traditional timber statistics. The use of pictorially-displayed forest information will be one of the most important additions to our management tools in the future.

Aggregation

Aggregation of existing information or sub-inventories is by far the most common for large countries like the Australia, Canada, and the United States. Smaller countries, like Tanzania, may also use this method. This is the technique ECE/FAO uses for global assessments of the temperate zones.

A central unit specifies the information needed or tables cooperators must complete. Participating elements collect the data for their areas of responsibility using any of the designs listed under the single method. The cooperating units, in turn, provide summary information to the coordinating unit. If the collaborating units belong to the same organization as the central unit, then there can be strong control. The directing organization specifies end product, sample designs, data collect techniques and standards.

The strength of the central or coordinating unit and the relationship to the contributors is paramount to the success of the inventory. A strong organizing unit with sub units belonging to the same organization as found in the USDA Forest Service, is one of the more stronger inventory structure possibilities.

If the participating elements belong to different organizations, such as that found in Canada and Tanzania, the control is less stringent. The accumulating organization specifies data required and when. Participating elements are free to use what ever data collection method they wish, as long as they can provide the necessary data to the required standards needed by the lead organization. National assessments based upon the accumulation of management plan inventories have been common in Central Europe.

The advantages of the aggregation technique are:

1. there is less impact on the cooperators. They are free to use whatever techniques that is suitable for the environmental, physical and economic situations they face.
2. there is less opportunities for conflicting data as the cooperating units provide the data for their lands.
3. there is less cost to the central unit as most of the expense is carried by the participating units.

The disadvantages are :

1. collaborating elements or the head unit may have to do considerable manipulation of the data before it can be combine and used for national reporting. required before the central unit can use it.
2. data may not truly be additive because of the different standards and techniques used or the time (reference year) when data are collected.
3. the error affecting the final outputs remains unknown at a fixed level of significance.
4. the quality of the final data or report is only as good as the weakest participating group.

Many of the problems of aggregation may be over come by using a low intensity sample to calibrate and monitor the aggregated data.

MONITORING

In addition to knowing how much timber is available and where it is located, most countries need trend information. We get trend data from monitoring. Monitoring is the periodic measurements or observations of selected physical, chemical, and biological parameters for establishing baselines and for detecting and quantifying changes over time. We can measure change simply by comparing two assessments of the same area performed at two different times. Most, if not all, nations have such a minimal monitoring program. More sophisticated schemes make use of networks of permanent sample plots. Many of the Scandinavian countries use networks of permanent plots for measuring change and predicting trends. According to personal correspondence with Aarne Nyyssonen, some Nordic countries are in their 8th survey cycles. France, The Netherlands, and Austria also have permanent sample plots (Lecomte and Rondeux 1992). We also have a network of permanent plots across most forest lands in the United States. Some have been measured as often as five times.

OUTLOOKS FOR THE FUTURE

We can safely predict that the Earth's population will continue to increase and our land base will remain essentially the same. There will be more pressure on our lands to produce more goods and services. With this pressure, it will be come increasingly important to maintain or improve soil, water, and air quality. This is done by maintaining or increasing world vegetation cover. Within vegetation cover, it will be increasingly important to maintain or increase biological diversity and economic diversity of the local population. More knowledge about our resources and lands and how they react to various management activities will become increasingly important at the local, national, and global levels. Our inventories must eventually cover all lands and resources and account for every hectare.

We can also forecast that our technical capabilities to inventory and monitor the lands and resources will also improve. The resolution, spectral separation abilities, frequency of coverage and overall availability of satellite-based remote sensing will increase. Mapping and monitoring of our resource base will be essential. The demands for information will increase, especially for information located spatially in geographic information systems.

Multiple Resource Inventories

Until about 1980, most national inventories of forest resources emphasized estimating the amount and extent of the timber resource. Since that time, public interest has placed increasing emphasis on the need to manage public forests for a variety of purposes and to recognize uses that have been on going since humans first set foot in the forests. In addition, decision-makers are using national inventories for environmental monitoring both at the local scale and at the global level. Now we need to look at all functions of the forests and the relationship of forest lands and uses to other lands and uses as well. We must start designing holistic, multiple resource inventories.

Multiple resource inventories (MRI) are data collection efforts designed specifically to meet all or part of the information requirements for two or more functions or sectors (Lund 1986). They offer advantages over single functional inventories in that MRI are more economical and provide more comparable data across the inventory unit.

Resource specialists have conducted multiple resource inventories on forest and range lands in the United States, and most of these by the U.S.D.I. Bureau of Land Management (BLM) and the U.S.D.A. Forest Service (USFS) (McClure et al. 1979). Foresters have also conducted multiple resource inventories in Australia (Vanclay 1990), Solomon Islands (Fearnside and Hibberd 1992), Sudan (Lund et al. 1990), Tanzania (Mgeni 1990), and Vietnam (Chat and Mon 1992).

Not only are multiple resource inventories needed, but today's decision makers at the national and international level need holistic inventories of all lands and resources. This is especially true when we want to monitor changes in land use and productivity. There is too much interaction and interchange of uses between agriculture and forest lands, for example, to consider them in separate inventories or monitoring efforts. In the tropics, farmers are rapidly converting forest lands to agriculture. One way to stop this is to find more ways of getting more yield from the agricultural lands. Thus the decision-maker needs more information on the existing agriculture lands. On the other hand, many of the agricultural lands in the temperate and boreal areas are being converted to forests. The decision-maker needs to know the capability of the agriculture lands to sustain given tree species.

Holistic, multiple resource inventories (MRI) are useful in the following situations:

1. If base data are completely lacking.
2. If data exists but there are conflicts with other efforts or if it is an obvious waste of funds to continue individual efforts.
3. If some good information exists, but it is incomplete in overlap areas between sectors, consider a multiple resource inventory to fill in. For example, forest inventories often do not include surveys of interspersed crop lands and vice versa. To manage these transition lands properly, the land administrator needs complete information. Always build on existing systems. Look for what is good and established and strive to make the existing systems more cost effective and utilitarian.
4. If agencies or ministries have established procedures and some ongoing efforts, but run into funding troubles, consider MRI to join expertise, reduce field costs, and duplication of efforts. Again build on the systems that are sound and established. Combining inventories that fall under the jurisdiction of one ministry are easier to coordinate those that fall under several ministries. In the latter, each ministry must feel they are a part of the MRI effort, benefit from the activity and share in the credit for its completion.

Global Connections

Not only must we develop holistic, multiple resource inventories, we must also consider how our national inventories provide input to global assessments. As there are two approaches to national inventories, there are also two approaches to global assessments. The first is an aggregation of national inventories. This is the technique being used by FAO/ECE. The second is for an organization, such as the United Nations, simply to conduct an inventory of the world's resources in a single effort. The latter is entirely possible using satellite-based remote sensing, existing information and limited ground sampling. The latter, however, is more politically acceptable especially if the global assessments also report on the resources of individual nations.

If future global assessments are to consist of aggregations of national data, then inventory specialist have to design the inventories to some minimum international standards and provide a core set of information. IUFRO S 4.02.05 Working Party is developing a set of Guidelines for World Forest Monitoring (Lund, Päivien, and Thammincha 1992). We will be refining these guidelines following this meeting. Once the guides have been reviewed and approved by international organizations like FAO and UNEP, then our tasks will be to design our national inventories accordingly.

Changing Technology

Lastly, we should also be designing our inventories to take advantage of new and emerging technologies such as satellite-based remote sensing, airborne videography, laser measurers, global positioning systems (GPS), and geographic information systems (GIS). We have already discussed some uses of satellite-based remote sensing in this paper. In addition to permitting us quickly, map large areas and to stratify our samples, satellite-based remote sensing allows us to pictorially-display the condition and distribution of our forests.

Airborne videography is a new technology that makes use of video cameras and aircraft to rapidly obtain digital imagery of small areas and then enter that information into a geographic information system. This technology is very useful for updating the status of forest cover and condition.

The USDA Forest Service has recently developed a laser tree measurer. This hand-held devise permits the accurate measurement and recording of tree heights and diameters as well as distances to objects.

A basic need is key all our plot locations (both temporary and especially permanent plots) with a coordinate system such as latitude and longitude or Universal Transverse Mercator (UTM) so we can enter the plot locations and data into a GIS and link our field samples with remote sensing. Global positioning systems (GPS) now allow us to navigate to and to locate plots in the field to within 25 meters anywhere in the world. Our ability to pin-point our locations will increase with the establishment of base stations, use of differential positioning, and new receivers.

Our pool of existing information will increase as well as our ability to access, manipulate, analyze data. Geographic information systems consist of computer hardware and software that enables us to merge all of the above technologies, manipulate the resulting data, and to analyze the information in a spatial context.

As we progress with developing more holistic inventories, linked to local, national, and global needs and employ the latest science, we will be better able to manage the Earth's resources. Kiitoksia paijon!

ACKNOWLEDGEMENTS

My thanks to Dr. Yong-Chi Yang - National University of Taiwan, Dr. Mark Hansen – USDA Forest Service, Dr. Simo Poso and Dr. Aarne Nyyssonen – University of Helsinki, Dr. Jacques Rondeux – Faculte des Sciences Agronomiques de Gembloux, Mr. Joe Lowe – Forestry Canada, Dr. Mohammed Ellatifi – FAO (Yemen), and Dr. Risto Päivinen – University of Joensuu, for their helpful suggestions for this paper.

REFERENCES

Baldwin, P.J.; Mathias, A.J.; Wood, D.J.; Bellamy, J.A.; Vanclay, J.K. 1992. Vanuatu national forest inventory. In: Wood, G.B.; Turner, B.J., eds. Integrating forest information over space and time. Proceedings of the International IUFRO Conference; 13–7 January 1992; Canberra, Australia. Canberra, Australia: ANUTECH Pty. Ltd.; 295–307.

Chat, Tran Van; Mon, Mai Van. 1992. Forest resources assessment and monitoring in Vietnam. *In: Lund, H. Gyde; Päivinen, Risto; Thammincha, Songkram; eds.* Remote sensing and permanent plot techniques for world forest monitoring. Proceedings of the IUFRO S4.02.05 Wacharakitti International Workshop; 13–17 January 1992; Pattaya, Thailand. Bangkok, Thailand: Aksorn Siam; 267–271.

Cunia, T. ed., 1978a: IUFRO proceedings on national forest inventory; 18–26 June 1978; Bucharest, Romania. Bucharest: Institutul de Cercetari Si Amenjari Silvice. 655 p.

Cunia, T. ed., 1978b: On the objectives and methodology of national forest inventory systems. In: IUFRO proceedings on national forest inventory; 18–26 June 1978; Bucharest, Romania. Bucharest: Institutul de Cercetari Si Amenjari Silvice; xi–xxviii.

Fearnside, A.; Hibberd, J. 1992. The Solomon Islands national forest resources inventory: an appropriate approach? In: Wood, G.B.; Turner, B.J., eds. Integrating forest information over space and time. Proceedings of the International IUFRO Conference; 13–17 January 1992; Canberra, Australia. Canberra, Australia: ANUTECH Pty. Ltd.; 330–342.

Gadant, Jean. ed., 1991: L'atlas des forets de France. Paris, France: Jean–Pierre de Monza. 240 p.

Gurnaud, A., 1897: Cahie d'ame'nagement pour l'application de la me'thode par contenance expose'e sur la foret des Eperons. Paris, France. 160 p.

Köhl, M. 1992. Proposed statistical design of the second Swiss national forest inventory. *In:* Wood, G.B.; Turner, B.J., eds. Integrating forest information over space and time. Proceedings of the International IUFRO Conference; 13–17 January 1992; Canberra, Australia. Canberra, Australia: ANUTECH Pty. Ltd. ; 308–313.

Langley, P.G., 1975: Multistage variable probability sampling: theory and use in estimating timber resources from space and aerial photography. PhD. dissertation, University of California, Berkeley. Diss. 75–22538. 101 p.

Lecomte, H.; Rondeux, J., 1992: Les inventaires forestiers nationaux en Europe: tentative de synthese. Les Cahiers Forestiers de Gembloux No. 5. Gembloux, Belgium. 35 p.

Loetsch, F.; Haller, K.E., 1964: Forest inventory. Volume 1. Statistics of forest inventory and information from aerial photography. Munchen, Germany: Bayerischer Landwirtschaftsverlag Gmbh. 436 p.

Lund, H. Gyde, 1984: The United States experience in the field of forest and range inventory. In: Encuentro national sobre inventories forestales. Memoria; 25–28 July 1984; Chihuahua, Mexico. Publicacion Especial No. 45. Mexico, D.F., Mexico: Subsecretaria Forestal; Instituto National de Investigaciones Forestales; 411–435.

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

Lund, H. Gyde, 1991: Present and prospective knowledge on usable forest resources. In: Proceedings Tenth World Forestry Congress; 16–27 September 1991; Paris: France. Nancy Cedex, France: Revue Forestier Francaise; 6:45–53.

Lund, H. Gyde; Mohil El Deen, F.A.; Allison, Ray P.; Jasumback, Tony, 1990: The Sudan reforestation and anti-desertification (SRAAD) project: applications for watershed management planning. Paper presented at the U.S. Agency for International Development/Bureau for Science and Technology Workshop on Environmental and Institutional Assessments for Watershed Management Planning. 26–27 June 1990. Washington, DC. 11 p.

Lund, H. Gyde; Päivinen, Risto; Thammincha, Songkram; eds., 1992: Remote sensing and permanent plot techniques for world forest monitoring. Proceedings of the IUFRO S4.02.05 Wacharakitti International Workshop; 13–17 January 1992; Pattaya, Thailand. Bangkok, Thailand: Aksorn Siam. 271 p.

Lund, H. Gyde; Thomas, Charles E., 1989: A primer on stand and forest inventory designs. Gen. Tech. Report WO–54. Washington, DC: U.S. Department of Agriculture; Forest Service. 96 p.

McClure, J.P.; Cost, N.D.; Knight, H.A., 1979: Multiresource inventories: a new concept for forest survey. U.S. Department of Agriculture; Forest Service. Research Paper SE–191. Asheville, NC: Southeastern Forest Experiment Station. 68 p.

Mgeni, Aaron S., 1990: Forest resources assessments in Tanzania: current inventory and monitoring methods applied, problems and possible futurology. In: Lund, H. Gyde; Preto, Giovanni, eds. Proceedings Global natural resource monitoring and assessments: preparing for the 21st century. 24–30 September 1989. Venice, Italy. Bethesda, MD: American Society for Photogrammetry and Remote Sensing; 546–556.

Pelz, Dieter R., 1991: National forest inventory systems in Europe. In: Köhl, Michael; Pelz, Dieter R., eds. Proceedings IUFRO Symposium – Forest inventories in Europe with special reference to statistical methods. 14–16 May 1990; Birmensdorf, Switzerland. Birmensdorf, Switzerland; Swiss Federal Institute for Forest, Snow and Landscape Research; 59–65.

Sharma, Eka Raj. 1992. Forest inventory in Nepal. In: Lund, H. Gyde; Päivinen, Risto; Thammincha, Songkram; eds. Remote sensing and permanent plot techniques for world forest monitoring. Proceedings of the IUFRO S4.02.05 Wacharakitti International Workshop; 13–17 January 1992; Pattaya, Thailand. Bangkok, Thailand: Aksorn Siam; 103–107.

Stott, Calvin B., 1968: A short history of continuous forest inventory east of the Mississippi. J. of Forestry 66(11):834–837.

Tomppo, Erkki; Siitonen, Markku. 1991: The national forest inventory of Finland. Paperi ja Puu 73(2):1–7.

Vanclay, Jerome K., 1990: Integrated resource monitoring and assessment: an Australian perspective of current trends and future needs. In: Lund, H. Gyde; Preto, Giovanni, eds. Proceedings Global natural resource monitoring and assessments: preparing for the 21st century. 24–30 September 1989. Venice, Italy. Bethesda, MD: American Society for Photogrammetry and Remote Sensing; 650–658.

Yang, Yong-Chi, n.d.: Evaluation of Forest resource inventory methods used in Taiwan. Unpublished paper. Taipei, Taiwan; National Taiwan University. 11 p.

NATIONAL FOREST INVENTORY BY AGGREGATION OF EXISTING INVENTORIES

Joe J. Lowe
Manager, Forest Inventory
Petawawa National Forestry Institute
Forestry Canada
Chalk River, Ontario, Canada

ABSTRACT

Canada's Forest Inventory is aggregated from various sources. Most of these sources are provincial management inventories based on forest type maps made from air photos. The national inventory takes advantage of an infrastructure of source inventories that are basically similar. Procedures have been developed to combine inventories with different specifications, and to overcome gaps in the data. The inventory in this form is now entering its third five-year cycle and uses modern computer technology to handle georeferenced data.

The Canadian approach is similar to that of the Global Forest Assessment of FAO/ECE, but differs from most of the older national forest inventories based on sample plots. The Canadian practice has several advantages such as cost relative to benefit, agreement between agencies, and opportunities to combine the inventory with other categories of spatially referenced information. There are disadvantages, too, especially the slow response to certain new information needs and some problems created by the different dates and specifications of the source inventories. The inventory cannot monitor change reliably. It is felt that the addition of a low intensity multi-level sampling scheme to monitor overall change would improve the design.

Keywords: Aggregation, Canada, forest inventory, national, sampling.

FOREST INVENTORY IN CANADA

Jurisdiction and Cooperation

Within the Canadian confederation there are 10 provinces and two territories. In this paper all 12 jurisdictions are treated as equals. Their characteristics vary considerably. The calculated average would be just over two million people living at the southern fringe of an area of 83.1 million ha, of which 37.8 million ha (45 %) are forested (Forestry Canada 1988) but only about 8.3 million ha (10 %) are suitable for and currently under timber management (Lowe 1991). Forest resource management is mostly a provincial matter, so by international forestry standards the average province might be comparable to a country having a small population but large resources of land and forest. Compare this with the whole Swiss confederation where more than 6 million people inhabit a total area of 4.1 million ha, of which 1.2 million ha (29 %) are forested (Anon 1988).

Of Canada's better quality forest, 11 % is under federal or native ownership, mostly in special areas like national parks and military or native reserves. Private owners hold 9 %, but the majority (80 %) is provincially owned (Forestry Canada 1988). Provincial forest lands may or may not be assigned to industry for timber harvest under a wide variety of agreements .

Most inventory for forest management purposes is, therefore, a provincial matter, and each province has major investments in this regard in organisation, technology, and data. The federal government, primarily through Forestry Canada, participated directly in the earlier development of these inventories. The present federal role is to support the provincial inventories and to fulfil national and international mandates with activities such as research and development, liaison, the national forest inventory, and other national forestry statistics.

There are many mechanisms of federal-provincial cooperation for inventory purposes. The most visible is the Canadian Forest Inventory Committee (CFIC), which is a forum for inventory specialists from all thirteen jurisdictions to meet, exchange information, and tackle problems of mutual concern. Communication has been improved with a glossary of inventory terms, now in its third edition (Haddon 1988). Procedures for aggregating the many provincial inventories into one national inventory have been developed with the CFIC's collective cooperation; working details are negotiated separately with each province.

Local Inventory

The typical forest management inventory in Canada is based on maps of about 1:20 000 scale made from stereo air photos. Volume estimates are generally added to each stand (forest type polygon) from regional volume relationships based upon temporary sample plots. Because of the large areas involved and their remoteness, only a small proportion of the stands can be visited at the time of inventory.

The inventory process usually takes place in a province over something like a 10- or 15-year cycle, and the new inventory progressively replaces the old. The inventories are designed for periodic planning at the management unit level, and must provide reasonable general information on every stand. Management inventories can also serve as a basis for subsequent local and more specialised operational surveys.

Although management inventories are designed to give the best current 'wall to wall' information that the funds available will allow, and local forestry staff have a good working knowledge of the inventory's accuracy and peculiarities, estimates of precision or of change are not usually available or expected in the balance of user priorities. The regions of greater activity tend to get the most frequent and intensive inventory attention. Lower interest areas may be covered by less intensive reconnaissance inventories.

Because specifications and standards tend to improve with each cycle, the new inventory cannot generally be compared with the old to estimate change. Permanent sample plots (PSPs) are not usually a direct component of Canadian inventories, although the products of PSP studies, such as growth and yield relationships, may be integrated with the inventory.

New inventory methods, such as spatially referenced data and image handling technology or the modelling of stand development, increasingly allow maintenance and update of an inventory until a new one is delivered. Inventory priorities and funding have been fuelled primarily by timber interests. Now Canadian forest management and inventory specialists are striving to sort out society's new expectations of the state owned-forest resources and to develop inventory techniques to handle these expectations. Above all they would like to get the extra funds necessary to upgrade this massive investment in information that starts to become outdated at the moment of delivery.

It is recognised that better basic descriptions of the forest vegetation, the site, and the activities taking place would all improve the ability to serve different needs They would also allow for better tracking and modelling to both update an inventory to the present and to project it forward in planning scenarios.

National Aggregation

Since the 1950s there has been a great investment in map-based inventories across most of the forested regions of Canada. Despite the differences over time, and between and within jurisdictions, there are many similarities. There has been a convergence of basic inventory characteristics through cooperative liaison and the application of similar techniques to similar problems. Forest inventory organisations were early operational users of computers to handle large stand lists and associated information. From the beginning it was an almost universal practice to break stands at map boundaries and to identify all data by map sheet.

Up to and including the 1976 national inventory, the practice was to collect and publish provincial level summaries from each jurisdiction. Standardisation in certain key topics was encouraged, especially through the conditions of federal contributions to provincial inventories and federal inventories of more remote areas.

In the 1970s the inventory specialists of the various jurisdictions met several times as part of a wider federally coordinated effort to rationalise and standardise the country's conversion to metric units. They found the meetings so beneficial that they continued as the Canadian Forest Inventory Committee. From the national perspective this has encouraged voluntary compatibility and a converging evolution of inventory methods. Cooperation of this sort generally minimises the political problems that would occur within a confederation of autonomous inventory agencies if federal authorities tried to impose standardisation.

Using geographic information system (GIS) technology, and capitalising on the circumstances described above, the 1981 national inventory (Bonnor 1982) collected, standardised, and aggregated data from the various source inventories by map sheet. Each map sheet was used as one of 43 000 'cells' in the national inventory. The target cell size was 10 km by 10 km, and this proved to be a very suitable level of resolution at national scales of about 1:20 million.

There are several characteristics of these cells and their associated data that are not immediately apparent.

- The cells are, in fact, irregular polygons because of the different sizes and systems for delineating the map sheets.
- The cells are not homogeneous, but contain as many records as there are unique combinations of descriptive attributes within that cell. As well as these descriptors, each record has area and wood volume statistics that come from the one or more stands within the mapsheet that contributed to that record.
- Although the cell is the visible limit of spatial resolution, the component records have not themselves been distorted by polygonal aggregation or diluted by sampling. They still represent the attribute characteristics of the source inventories. In other words, although there has been a major reduction of spatial resolution (from about 1:20 thousand to 1:20 million) there has been no generalisation of attributes, although they have been reduced, re-coded, and standardised from the numerous source inventories. In the 1986 inventory there were 37 source inventories.
- The national inventory is a complete census of stands – it is not a sample.
- This level of detail is used as building blocks for regional or national statistics, choropleth theme maps, and national spatial studies. It is not suitable or approved for intensive local examination, and such requests are directed to the more detailed provincial source inventories.

The 1986 inventory, which is now on line (Forestry Canada 1988; Gray and Nietmann 1989), and the 1991 inventory, which is in preparation, improved progressively in content, quality, and process, but their principles were the same. For the 1991 inventory the basic production steps are:

- Conversion – the relationships between each provincial inventory and the national inventory in such matters as terms and classes are explored and documented.
- Re-coding – the provinces with new inventory data to contribute extract that data and re-code it to national standards.
- Quality check and aggregation – the data are checked rigorously, and aggregated from the stand to the cell level.
- Missing values – not all source inventories can deliver data for every attribute in all situations, so many of these 'holes' are being filled by calculation using local knowledge. The products of such calculations will be clearly identified in the record.
- Auxiliary information – some other categories of regional information that are not part of the source inventories are combined with the national inventory to calculate new attributes.

SOME OTHER NATIONAL AND GLOBAL INVENTORY DESIGNS

Sample Plot Networks

Many national forest inventories of temperate countries involve a network of sample plots. The Nordic countries, the USA, and China are good examples. Many of these nations are well represented at this symposium, so this paper need go no further into a description of their designs. Most of the inventories use permanent sample plots subject to remeasurement and so make good estimates of change, although our Finnish hosts have developed an interesting variation on this theme.

These kinds of inventory have many advantages and some disadvantages as discussed below. They are beloved of statisticians and textbooks, and are well documented. Some authors even use 'NFI' (national forest inventory) as a synonym for this type of inventory and appear to be unaware of other designs.

Aggregation

The Canadian Forest Inventory is the second largest aggregation-type inventory in the world in terms of area, and is arguably the most advanced and complex. The periodic Global Forest Assessment of UN/FAO/ECE is the largest in terms of area. It is aggregated from the source inventories of contributing nations, including Canada.

Australia is another large, decentralized, and relatively new country that is technically advanced. The forest resource is relatively small but important, and the several state inventory systems are improving rapidly. Many of the questions for which the national inventory should provide answers are still not clear because of the evolving balances between: state and commonwealth jurisdictions; industrial, environmental, conservation, and other values. The new National Forest Inventory of Australia is sensibly buying time by developing national overviews by aggregation of state and regional inventories while they test such things as specifications, standards, techniques, resources, and political will.

Other Designs

Although it is not germane to this paper, it should not be forgotten that there are other basic approaches to national inventory design and, of course, not all countries have national forest inventories.

Recent developments in the collection and analysis of low resolution digital remote sensing from satellite platforms are being used in several attempts to map and monitor the forests of the world in general and certain countries in particular. The author is sceptical about calling some of them 'national inventories' because they seem to be long on remote sensing and short on links to what exists and is important on the ground. However, there is no doubt that there are some great opportunities for extensive and relatively cheap national inventories based on multi-level data from satellites down to field plots. The satellite imagery would contribute the highest level of information, be it with sample points or classified map strata.

SOME ADVANTAGES AND DISADVANTAGES OF SAMPLE PLOT AND AGGREGATION APPROACHES TO NATIONAL INVENTORY

Hierarchical Data

The aggregation approach has two linked advantages. One is that the upward migration of data in the hierarchical pyramid allows agreement between jurisdictional levels. This was one important factor in selecting aggregation rather than independent sampling as the basis of design for Canada's national forest inventory. There could be serious problems if provincial and federal estimates did not agree. Linked to this is the advantage that the national estimates are to the same inherent resolution and specifications as those used by the forest managers.

Cost

Aggregation from existing inventories is much cheaper than independent sampling, especially when experience, hardware, software, and documentation have been acquired from previous inventories. Exact figures cannot be quoted, but the cost of a few hundred thousand dollars per year for Canada's aggregated national inventory can be compared with a few million dollars per year for the sampling inventory of the smaller USA. These differences in cost are justified by parallel differences in the needs for information.

Timeliness

One weakness of Canada's aggregated inventory is that the data are the best available in the source inventories at the time of collection. Thus the average age of data collected for the 1986 inventory was 10 years and it is not practical to update the national inventory by calculation. However, it should be noted that the provincial forest management inventories, from which the national inventory is aggregated every five years, are improving rapidly in their incorporation of change to keep them more up-to-date. The 1991 national inventory will include, for the first time, one large area (British Columbia) where source inventory data for the whole province has been updated by observation or calculation to 1991.

This situation appears to compare unfavourably with sampling inventories where current data are collected at the time of measurement, and the data allow updating by calculation between measurements. In Canada's case it can be argued that the distaste for old information has been learned at the stand and management unit level, but it is much less significant when it comes to national level statements. It is also worth noting that the oldest information is in areas where forest management activity is extremely low, whereas areas of high activity tend to be re-inventoried more frequently.

Monitoring

The inventories based on re-measurement plots can monitor change extremely well. This is perhaps the weakest aspect of Canada's national inventory. The provincial update activities mentioned under 'Timeliness' above are geared to maintaining the best possible local inventory as pieces of information become available, and these activities may include both the observation and the modelling of change as well as the correction of observed errors. They are not designed primarily to estimate change.

Estimation of Error

Sample plot inventories are designed to allow estimation of error, whereas the typical Canadian map-based inventories are not. This ability has been foregone in the development of 'best value, best available', complete, site-specific coverage of very large areas. Scientists and statisticians dislike estimates that do not include sampling error, but the unfortunate truth is that limitations of statistical science and other practical realities preclude this luxury from most of the important decision-support information in the world at present.

It is recognised that the two weaknesses in Canada's inventory concerning estimation of error and monitoring could both be overcome for a few key attributes at the national level with a relatively cheap sample within the frame of the inventory. Such a low intensity sample would probably use remote sensing plots in a multi-level design with the minimum possible number of expensive ground plots.

Detail

The aggregation method has more detail in that every mapped stand is included, although spatial resolution is limited to the cell. In sample plot inventories only those stands within which a plot falls are recognised. On the other hand it should be noted that the sample plot inventories can carry more attribute detail down to the single tree level, whereas Canada's forest inventory cannot go directly to many within-stand attributes.

The spatial resolution for map displays of the aggregated inventory is the size of the mapsheet cell, which in Canada's case is about 430 000 cells of something over 10 000 ha each. The spatial resolution of the sample plot inventory is a function of the density of the plots, which in Switzerland's case is about 41 000 points representing 100 ha each. Of course, one Swiss plot will sample one condition, whereas one Canadian cell may contain between 10 and a hundred records representing all the forest in that cell.

The sample plot inventory has the distinct advantage that any detail of interest can potentially be collected, whereas the aggregated inventory is restricted to those available in the source inventories. This leads to the problem of missing values, although these are being progressively reduced in Canada with newer and more comprehensive source inventories, as well as with the procedures mentioned above to calculate some of the missing values.

New Attributes

Further to the previous comments, sample plot inventories can respond much more quickly in the collection of new attributes. Thus the US Forest Service inventory is very impressive in its ability to handle new topics like forest health. An aggregated inventory such as Canada's may have to wait until a significant number of source inventories have seen fit to introduce the new attribute, and it takes several years for a significant portion of those inventories to be renewed and become available.

New attributes can also be calculated from, or estimated by association with, Canada's national inventory. The associated data can be linked to the inventory by attribute or location.

CONCLUSION

Any country that is considering starting a new national inventory, or modifying an existing one, must consider the needs, the costs, local circumstances and practices, and the technology available at the time. The great advantage of a symposium such as this is to meet other experts, to learn what they are doing and why, and to consider how to improve matters. It may be a fruitless but interesting experience to dream about your own national inventory and how it might be designed if you could start from scratch with today's knowledge and technology.

Sophisticated statistical designs could possibly make use of existing inventory and management information that is aggregated in combination with remote sensing and permanent ground plots. There must be one of Murphy's Laws which states that the greater the level of design sophistication the greater the chance for accident! Sophistication should not be acquired at the expense of robustness and versatility.

REFERENCES

Anon, 1988: Inventaire forestier national suisse, résultats du premier inventaire 1982–1986, cartes thématiques 1:800 000. Annex to report 305, Swiss Federal Institute of Forestry Research.

Bonnor, G.M., 1982: Canada's forest inventory 1981. Dep. Environ., Can. For. Serv., For. Statistics and Systems Br.

Forestry Canada, 1988: Canada's forest inventory 1986. Can. Govt. Publishing Centre.

Gray, S.L. and Nietmann, K., 1989: Canada's forest inventory 1986: technical supplement. For. Can., Petawawa Natl. For. Inst., Inf. Rep. PI-X-86.

Haddon, B., ed., 1988: Forest inventory terms in Canada, 3rd edition. Can. Govt. Publishing Centre.

Lowe, J.J., 1991: Canada's forest inventory: the sustainable commercial timber base and its growth rate. Proc. nat. conf. Canada's Timber Resources, For. Can., Petawawa Natl. For. Inst., Inf. Rep. PI-X-101.

A BLUEPRINT FOR FOREST RESOURCES INVENTORIES IN THE UNITED STATES

James T. Bones
Branch Chief
Forest Inventory and Analysis Research
USDA-Forest Service
Washington, DC, U.S.A.

ABSTRACT

For over 60 years, the Forest Inventory and Analysis Research Program (Forest Survey) has played an integral role in the management of the timber resources of the United States and in the orderly inventory of these resources which is required for the development of effective management scenarios. It has helped to guide industrial expansion and identify problems already created or developing in the timber supply. During this time, the program has been internally motivated to improve the reliability and usefulness of the forest resource statistics and the analysis of research findings

A new and broadened mission is being developed to address current and future information requirements. Along with the new mission, an action plan will be implemented to chart a course for the Forest Inventory and Analysis Program that will serve as a guide throughout the 1990's. The new direction covers three traditional research areas and two new areas designed to answer questions of emerging forest resource concerns. Guiding principles for the program and goals for the 1990's are being redefined.

Keywords: United States, forest inventory, future vision, blueprint.

INTRODUCTION

Since its beginning, Forest Inventory and Analysis (FIA) has played an integral role in the management of the Nation's timber resources and in the orderly inventory of these resources which is required for the development of effective management scenarios. It has helped guide industrial expansion into the most suitable and opportune locations. It has acted as watchdog in identifying problems already created or developing in the timber supply. It has provided key forest resource information for planners and policy makers, and has also provided expert advice and assistance in solving complex resource questions.

It has been internally motivated to improve the reliability and usefulness of forest resource statistics and the analysis of resource findings. In recent years, an increased number of major decisions affecting the Nation's forests have been made with reference to and reliance upon Forest Inventory and Analysis findings and forest resource evaluations.

High standards set in its early days and maintained over the years by FIA, have established a tradition for full, unbiased, and factual presentation of forest resource information. These same high standards must be sustained in the future if FIA is to retain its credibility and usefulness. Therefore, all change, expansion, or shifts in program emphasis must be made with utmost care to insure that all information produced is based on adequately tested procedures and sound research.

It is with this background that the Forest Inventory and Analysis program proposes to approach the formulation of a new and broader program for the future.

MANDATES

The Forest Inventory and Analysis program, initially known as the Forest Survey, was conceived over eight decades ago when the U.S. Congress acknowledged the need for information about the supply and condition of the Nation's natural resources. The Organic Act of 1897, which established the National Forests, included provisions for the inventory and management of these lands. Later, the Forestry Research Act (McSweeney-McNary) of 1928 directed the Secretary of Agriculture to make and keep current a comprehensive inventory and analysis of the Nation's forest resources. The Resources Planning Act of 1974 (RPA) amended the earlier research act and directed the Secretary of Agriculture to, "make and keep current a comprehensive inventory and analysis of the present and prospective conditions of and requirements for the renewable resources of the forest and rangelands of the United States.." The Forest and Rangeland Renewable Resources Research Act of 1978, which replaced the earlier Forestry Research legislation, repeated the amendment contained in the RPA.

The National Forest Management Act of 1976 states "to serve the national interest, the renewable resources program must be based on a comprehensive assessment of present and anticipated uses, demand for, and supply of renewable resources from the Nation's public and private forest and rangelands.." This law expanded the activities of the nationwide Forest Survey to cover all renewable natural resources. Recent legislation, such as the Forest Ecosystems and Atmospheric Pollution Research Act of 1988, directs the Secretary of Agriculture to "increase the frequency of forest inventories in matters that relate to atmospheric pollution and conduct such surveys as are necessary to monitor long-term trends in the health and productivity of domestic forest ecosystems". This legislation directs FIA to monitor the forest health of the Nation. In cooperation with State and Private Forestry, under the Forest Stewardship Act of 1990, FIA is developing a methodology to assess the current status of the urban forest resources of the Nation.

MISSION

To improve the understanding and management of our Nation's forests by maintaining a comprehensive inventory of the status and trends of the country's diverse forest ecosystems, their use, and their health.

PURPOSE

The purpose of this action plan is to chart a course for the Forest Inventory and Analysis program that will serve as a guide throughout the 1990's. It contains the basis for our varied activities, covers our relationships with our clients and cooperators, and contains our vision of where we are, and where we are going. We are proud to be part of the USDA-Forest Service whose stated mission is "to care for the land and to serve the people". We have an important role to play in achieving this overall mission. Our forest inventories provide the necessary foundation for building a program of land stewardship. And we serve the people by providing unbiased, accurate, current, and relevant forest resources information that meets their diverse needs. Likewise, we are proud to be part of the Forest Service Research organization that serves society by "developing and communicating the scientific information and technology needed to protect, manage, and use the natural resources of forests and range lands". As part of Research's foundation program, we develop basic statistics that are needed as background for many research proposals and problem analyses. Although much of our energy is expended in data gathering and reporting statistics, our program includes a dedicated and capable cadre of scientists who evaluate forest resource trends, develop techniques, and adapt the latest technology to allow us to remain in the forefront of inventory organizations throughout the world. As our mandated responsibilities grow and our client base becomes more diverse, FIA must become more responsive to the public's information needs.

Issues and trends

Long Term – Four issues stand out as being related to renewable natural resources and will directly affect the FIA program.

Increasing Pollution includes such topics as acid precipitation, the effects of global climate change, deterioration of forest health, and lower forest productivity.

Dwindling Resources encompasses lack of regeneration, overharvesting, desertification, a loss of biological diversity, dwindling old-growth forests, and forest and ownership fragmentation.

Increasing Population is closely linked to urbanization, land clearing, and increased pressure on remaining forest systems to supply necessary goods and services.

Proliferation of information of information concerns the need for accurate, timely resource information and easy access to data.

Short Term – We must anticipate research needs rather than react to crises. To do this, we must be aware of upcoming trends. For the 1990's, we see the following major trends affecting forest resources:

A Changing Forest Land Base – The ability of our forests to supply timber products is declining in response to growing pressures to supply a broad spectrum of commodities and nonmarket goods and services. To keep pace with dynamic land-use change, the inventory remeasurement cycles should be shortened and appropriate variables should be collected to adequately characterize other resources values.

Rising Noncommodity Uses – The extent and condition of forest resources, on which these uses depend, needs to be thoroughly documented. In-depth analyses are needed to estimate outdoor recreation demand and potential increases in use, wildlife habitat suitability and extent, watershed conditions, grazing use, and biological diversity. To get a complete picture of these resources, all forest land, including wilderness areas and parks, should be included in forest resources inventories and featured in reports.

Environmental Health Change – Forest health and productivity are affected by a large number of interacting factors. Air quality problems and the potential for anthropogenic climate change have increased the need for timely information on the health and productivity of the Nation's forests. Addressing these issues requires efforts from many disciplines to provide new kinds of monitoring data. A key role will be the establishment of a baseline set of field locations that can be monitored to detect changes in the health and condition of major forest ecosystems over time.

ALLIANCES

The FIA program has many partners in accomplishing its mission. Some traditional and major current cooperators and their relationship to our program includes:

Forest Service -NFS – National Forest Systems administrators are major land managers, especially in the West, and are responsible for intensive management-level inventories on National Forest lands. In the East, the FIA program conducts extensive inventories on the National Forests, as well as other public and private land, and furnishes standard statistics for Resource Planning Act (RPA) decadal assessments. In the West, NFS furnishes input for State-level inventories and RPA assessments.

The two inventory activities are complementary. Land management questions can best be answered by map-based NFS inventories, while questions that are regional in nature and that effect all forest land ownerships can best be answered by the FIA sample-based inventories. As the Forest Health Monitoring program is implemented, FIA will be establishing and maintaining these field-plots at FIA photo- or field-plot locations on all forest land ownerships and thus will have opportunities to strengthen our partnership with NFS.

Forest Service-S&PF – State and Private Forestry programs offer opportunities for cooperation in several areas. Forest Pest Management (FPM) is a major partner with FIA in implementing the national Forest Health Monitoring program. The FIA role is in the early phases of monitoring; answering questions of what, where, and when by recording the condition of forest ecosystems, estimating baseline conditions, and detecting changes from the baseline. FPM assists in detecting changes and takes the process one step further by determining the causes of the detected changes. When cause is identified, then corrective actions can be identified and implemented.

Under the Forest Stewardship Act of 1990, "an assessment of the current status of urban forest resources" is required. No uniform national methodology has been developed for conducting these assessments. FIA has the technical skills and design capabilities to develop this methodology, and a nationwide organization that is capable of producing consistent national statistics. The Tropical Forestry program recruits experts to assist in training professionals from developing countries and helping them to manage their forests for sustainable development. FIA scientists are experts in resource inventories and analyses and the application of GIS and remote sensing technology to resource assessment needed for this program.

States – The States have a long tradition, both directly and through the National Association of State Foresters, of providing cooperative assistance to the FIA program in many forms. Individuals within State agencies serve on important forest inventory advisory committees. During periodicreinventories. States may provide financial support to intensify the sample intensity. State personnel provide training to FIA field crews in insect and disease detection, provide manpower, field equipment, vehicles, and aerial photography for both forest inventory and forest health monitoring activities. State Forestry staffs also assist FIA in gathering commodity drain and forest landowner data at specified intervals, and they review forest resources reports and assist in disseminating results to the clients and data requesters.

Forest Industry – Forest industry has long been an active cooperator with and supporter of the FIA program. Forest industry provides FIA access to fee and leased forest lands to conduct inventories and forest health monitoring. They participate with FIA through the Research Committee of the American Forest Council to provide review and advice on technical inventory matters. Industry is a major user of FIA resource inventory data, and both individually and collectively, are active supporters of the FIA program.

Soil Conservation Service – A formal agreement between the SCS and FS states that "Forest Service will be responsible for forest resource inventories" and" FS and SCS will work together on inventory...to identify data needs, avoid duplication of efforts, and assure that data collected by each agency are mutually useable." It further states, that SCS and the FS will "...develop common methodology and standards, and broaden opportunities for sharing information." In recent years, cooperation during several statewide inventories has resulted in the verification and upgrading of SCS soils maps and the addition of soils information when evaluating forest productivity. The two agencies both have inventory responsibilities and plan to cooperate closely during current and future SCS National Resources Inventories and FS Resource Planning Act Assessments.

Environmental Protection Agency – The Forest Service is cooperating with the EPA-EMAP-Forest program in the continued development and national implementation of forest health monitoring. Detection monitoring, one of the three tiers of inter-related monitoring activities, is the most extensive level and involves the FIA program. Detection monitoring provides a direct linkage to the EMAP sampling grid. EPA and FIA scientists are collaborating in specifying the monitoring requirements for forest ecosystems. EMAP-Forest will also provide ancillary data that will help in interpretation of detection monitoring results. Over the next five years, we envision that the planning and implementation of the nationwide monitoring program will be completed.

During this period EPA will contribute funding, training, staff, and laboratory analysis for samples collected in the field.

Conservation Groups – In recent years, conservation groups, including the Wilderness Society, Friends of the Earth, Audubon Society, and the Sierra Club, have made increasing use of FIA multiresource inventory data and analyses. With increased recognition of the value and uses of this information, these groups and others will become active supporters of the FIA program. These groups provide useful guidance on how to inventory and assess forest resources more effectively.

Universities – The universities participate actively in recruitment of students for both seasonal and permanent FIA positions. In addition, researchers at universities are involved in formal cooperative agreements with FIA research units for research and analysis using resource inventory data. Forestry extension activities at universities are an important means for transferring FIA findings and technology.

RESEARCH DIRECTION

Recent mandates provide Forest Inventory and Analysis with a new charter for the 1990's. More importantly, however, is our recognition that the various pieces of new legislation offer tremendous new opportunities for the Forest Service, the Research Stations, and other researchers as well as the Forest Inventory and Analysis program. In the past, Forest Service researchers have worked somewhat independently of one another, each pursuing individual and often unrelated goals within a single discipline. In addition, much research has been conducted as case studies applicable only to local situations, and as a result, cannot be expanded to broader regional applications. When making regional resource evaluations, another problem is that individual disciplines or specialties tend to develop their own terminology, standards, and methodology, often inconsistent with other disciplines. This lack of comparability makes it very difficult, if not impossible, to relate results to a common resource situation or common land base.

Collectively the Resources Planning Act, Forest Ecosystems and Atmospheric Pollution Research Act, and the Forest Stewardship Act offer an opportunity to develop a strong, coordinated research effort dedicated to meeting the special needs of the Acts, and at the same time, provide motivation for many different specialists and disciplines to work together toward common goals.

Within this context, Forest Inventory and Analysis proposes an expanded research program in 3 traditional areas of emphasis and a new research program in 2 areas of national concern.

Traditional Research Areas:

1. Comprehensive Inventory of the Forest Ecosystems of the United States

Forest land covers 731 million acres, or 32 percent of the land base in the United States. These forests provide important economic, social, and aesthetic values to the Nation's 250 million inhabitants. Comprehensive inventories will be planned and conducted to provide current information on the extent, condition, and use of the renewable forest resources. Focus will be on the efficient collection and compilation of forest resources data required for periodic national assessments and statewide resource evaluations. Research and analysis of past, current, and prospective trends in the renewable forest resources as they relate to the Nation's overall economic and social needs will identify the value and importance of all of the forest resources, note the interactions among various management activities, and identify opportunities for altering prospective trends. Timely, accurate, and comprehensive data for the forest ecosystems in the Nation are essential for the formulation of sound forest management policies and programs. In response we will:

- Identify new kinds of information that better describe the forest resources, and the landowners that control them.
- Obtain baseline data on forested wetlands and old-growth forests across the Nation and develop analytical methods for portraying them.
- Undertake the inventory of woodland and productive reserved forest lands of the Nation.
- Improve techniques and procedures for measuring biomass on forested and other land and estimate amount of carbon stored in forest ecosystems.
- Develop procedures to quantify landscape features when addressing fragmentation and other issues pertinent to contemporary management concerns.

2. Identification of Non-Commodity Variables Needed for the Nation's Resource Planning Act Assessments

Starting in 1976, particular attention was given to link variables indicative of more than one forest condition or attribute. Classifications andmeasurements made at sample locations focused on special information needs for evaluating wildlife habitat, recreation use, range suitability, water quality, erosion hazards related to forestry practices, and the use-interaction relationships associated with the numerous forest conditions.

The primary goal of a comprehensive inventory is to quantify and describe these distinct plant communities as to site, origin, vegetative composition, stage of development, and to determine what benefits are present. The inventory merges information on the understory plant communities and noncommodity attributes with conventional information on trees at the same sample locations. The inventory further quantifies and describes man's intervention and control over the natural development of these plant communities through conventional forestry practices and actions. In essence, the comprehensive inventory is designed to establish the basic ecological relationships vital to periodic assessments and evaluations.

To meet the challenge, we will:

- Develop closer alliances with diverse multiresource data users.
- Assist NFS in developing definitions, field procedures, and analytical methods for portraying old-growth forests ecosystems.
- Develop data requirements, definitions, and analytical methods to assist in evaluating wildlife habitat condition and extent, measuring biological diversity, and tracking threatened and endangered species.
- Expand the basic inventory of trees to include all vegetation for the purpose of establishing a long-term, statistically valid sample of condition of the entire forest ecosystem.

3. Forest Industry and Timber Production Analyses

Studies of timber products output will be conducted in cooperation with State forestry agencies, forest industries, and professional and trade associations. These data and data obtained from extensive inventories will allow scientists to plan and conduct research studies on timber use and its relation to inventory volume, and to estimate the amount of logging residues and other removals associated with cultural practices and changes in land use. Timber recovery studies and forest products and timber industry production information provide the necessary input for maximizing investment returns. Legislators, and public and private resource managers, planners, and analysts utilize this information to formulate policy and to make resource management decisions.

In response we will:

- – Conduct thorough analyses of change between successive inventories, examining gross growth, mortality, and removals.
- – Estimate and analyze changes in timber utilization.
- – Conduct studies of total roundtimber removals from all lands.
- – Conduct analyses of biomass/energy potentials and their impact on traditional timber uses.

New Research Areas

4. Implementation of Forest Health Monitoring

The USDA Forest Service and the Environmental Protection Agency are jointly developing a forest monitoring program to provide regional assessments of the status and trends of forest condition. As an initial step in the development of this program, a pilot study on five indicators of forest condition (growth efficiency, visual symptoms, foliar nutrients/chemical contaminants, soil productivity, and vegetation structure) were conducted during the 1990 summer field season in New England. These indicators are being considered for use in the remaining eastern states and in the West as the program is implemented in future years.

Our efforts will include:

- – Investigating forest sampling strategies that are best suited to forest health monitoring.
- – During analyses, determining how to link forest health data collected in the field, remotely sensed data, and other data (e.g. climate parameters and pollution loadings).
- – Identifying key environmental health indicators which directly, or indirectly, reflect forest ecosystem condition. Determine if forest indicators discriminate between forest stands of known "good" and "bad" health.
- – Determining how to monitor and track long-term trends in the health and productivity of the forest ecosystems.
- – Identifying the field data measurements required to adequately assess both human-induced and natural environmental stresses.
- – Developing sound mensurational and data processing procedures applicable to forest health monitoring.
- – Conducting studies to determine the kinds of information that can be acquired from remote sensing.

5. Urban Forest Inventory Research

Backyard forests and single/ groups of trees in urban/suburban settings are receiving increasing attention as a source of wildlife habitat, specifically for songbirds and small mammals in predominantly urban or suburban areas. Small forested tracts, that do not meet FIA's definition of forest land, are being used as inner-city environmental education centers. Greenways are increasingly used by city dwellers as a focal point for recreation, exercise, and other leisure activities. In addition, research is currently being conducted to identify the tree species that are best suited for planting as windbreaks, noise barriers, to abate hydrocarbon emissions, and as potential for summer shade to reduce energy costs in cities and suburbs. A baseline estimate of tree biomass in urban settings is necessary to be able to monitor the effectiveness of urban tree planting programs and to identify the size and species distribution of trees. Cities and urban land should be first stratified into sub-classes, such as residential, transportation rights-of-way and median strips, recreational greenways, and industrial settings, so that biomass estimates, and the extent and type of use associated with the subclasses, may be identified.

To meet this challenge, we will:

- Develop a methodology for delineating and stratifying "Urban Forest Land".
- Test, and if necessary, modify existing procedures of land classification and estimation in order to conduct forest/tree inventories in densely populated areas.
- Evaluate the extent of forest urbanization at present, track changes in "urbanized forest land", and evaluate the effects of urbanization on levels of forest management and ecosystem retention.
- Design appropriate sampling procedures to study ecological systems along urban-rural gradients and to examine remnant forest patches, species composition, and vertical and horizontal vegetative structure.
- Investigate new ways of describing the urban forest, such as leaf area indices or foliar volume.
- Develop total tree biomass equations for urban trees by evaluating crown structure and relating canopy biomass to stem diameter for trees in urban settings. Determine the current extent and distribution of tree biomass, by species and size.
- Identify the level of use and the extent of management for recreation and wildlife habitat associated with urban land uses, such as backyard forests, land supporting trees and shrubs but less than 1 acre in size, and strips of isolated trees along fences and streams in agricultural settings.
- Evaluate the current levels of removals and mortality of trees in urban land uses and develop trend data by species and land-use classes.
- Assess the impacts of urban expansion and other developments on the forest resources. Provide information on the forest area and tree volume found in close proximity to areas developed for permanent or seasonal homes, campgrounds, recreational resorts, and industrial complexes.

GUIDING PRINCIPLES

In implementing this new and expanded plan of work, we will be guided by the following principles:

- Although our primary mission is to serve the people of this Nation, we recognize that many of the problems require a multinational or global approach.
- We will take the lead in inventorying and monitoring changes in the Nation's forests, forest resources, and forested ecosystems.
- In regard to common national and international data reporting problems, we will strive to establish universal protocols that assure comparability of statistics.
- We will operate to maintain the best possible working relationships with our clients and cooperators.
- We will actively participate in developing inventory methods and new techniques that will assist the National Forest System in meeting the requirements of the National Forest Management Act.
- We will maintain our emphasis on conducting statewide forest resources inventories, while conducting a balanced program of research to advance knowledge on multiresource assessments and forest health monitoring.
- We will recruit, train, and retain a competent and highly dedicated work force from all segments of the Nation's population, and we will encourage creativity and innovation in our people.

GOALS FOR THE 1990s

In the short term (the next 5 years) the FIA program will concentrate on attaining these general, high-priority program goals:

Base Program

1. Maintain maximum 10-year inventory remeasurement cycle in all regions.
2 Expand FIA comprehensive inventory coverage to all forest lands, regardless of status or ownership.
3. Develop and maintain data bases and a uniform data delivery system to address State, regional, and national forest-resource information issues, and provide adequate documentation and interactive access for data requestors.

Forest Health Monitoring

1. In cooperation with EPA, the States, and other federal agencies, establish and maintain an extensive Forest Health Monitoring network across all forest ecosystems.
2. Identify, measure, and monitor key indicators of the forest that allow an assessment of forest productivity; resiliency; biodiversity; and ecosystem stability, distribution, condition, and structure.

Techniques Development

1. Implement research and technical development of inventory and monitoring design and resource analysis methods.
2. Identify those remote sensing products, or combination of products, best suited for monitoring forest area change in the United States.
3. Develop appropriate methods for identifying, defining, and inventorying urban forests and forested wetlands.
4. Validate most appropriate methodology for estimating the components of change and its use during extensive forest inventories.

Other Activities

1. Maintain and update the 1987 RPA Assessment data base and statistical summary tables for 1992.
2. Update the national survey of forest land owners of the United States
3. Expand the national biomass assessment to include the western woodland ecosystems.
4. Provide technical experts to assist international agencies and developing nations in conducting forest resources inventories and adapting emerging technologies.

THE SWEDISH NATIONAL FOREST INVENTORY – A REVIEW OF AIMS AND METHODS

Gustaf von Segebaden
Professor, Dr. of Forestry
Department of Forest Survey
Swedish University of Agricultural Science
Umeå, Sweden

ABSTRACT

The paper gives a broad review of aims and methods in the Swedish National Forest Inventory, from the first inventory 1923–1929 up to the plans for the seventh inventory 1993–2002. In the beginning the inventory was concentrated towards forest- and timber resources, thereafter towards changes in the forest resources. As time went on the inventory has been extended to cover not only forest conditions but also environmental conditions in general.

At the same time the inventory method has changed from a strip survey of one or more counties each year to a systematic inventory with both permanent and temporary plots which annually cover the whole country. In the middle of the seventh inventory 1993–2002 remote sensing should, according to the plans, be operationally introduced. Then it will be possible to give "up to date-information" for areas of variable size and the results can be used as a basis for local management planning.

Keywords: Forest inventory methods, forest resources, environmental conditions.

The Swedish National Forest Inventory (NFI) was started in 1923, but the initiative for a complete forest inventory was taken 15 years earlier. The two questions to be answered were as follows:

- How large is the annual growth in Swedish forests?
- How large are the quantities of wood removed annually from Swedish forests?

The circumstances were that prior to 1923, from a starting-point of highly variable basic data, instead of "direct, systematic investigations", growth had been calculated to approximately 21 mill. cubic metres a year and the timber consumption to 39 mill. cubic metres. Thus, it appeared that the deficit, i.e. 18 mill. cubic metres, was almost as large as the annual growth.

It was against this background that the first inventory between 1923–1929 concentrated on forest- and timber resouces. The issues concerned were the area and quality of forest land, and the forest's development structure, standing volume and growth. Reports were carried out for each county and, in some cases, for larger parts of a county as well as for highland forests and river areas (the main part of the long distance haul was carried out by floating timber along the rivers).

The inventory involved a systematic strip survey with a lower degree of intensity in the north where the counties are large and the topographical variation is small, and a higher intensity in the south where the counties are small and the topographic variation is greater.

The field work was carried out for one or two counties each year.

Growth proved to be approximately 50 mill. cubic metres a year instead of 21 mill. cubic metres. The issue concerning the size of the removals, however, could not be solved by the NFI. Instead, an answer had to be obtained indirectly from statistics on timber consumption.

The second NFI 1938–1952 had much in common with the first regarding aim and design. Obviously, however, not only the state of the forest itself was under scrutiny, but also the changes between the inventories. Furthermore, the aim was to assess the state of the forest in the possession of various categories of forest owners (the State, Limited companies, etc.).

In addition, there was a demand for a higher precision, to enhance the statistical accuracy of the results produced. As a consequence, the earlier strip survey was developed into a combined strip and sample plot survey.

During the course of the second inventory, a major administrative organizational change took place. In 1943 the NFI was transferred to the National Forest Research Institute. The reason for the transfer was to estblish close relationship between the forest survey and the research at the institute. This was a satisfactory development for both parties. Prior to this, NFI:s had been conducted by appointed national committees. This close connection between the NFI and the forestry research appeared to bode well for future prospects!

At the end of the 1940's, a demand for improved, annual logging statistics was raised from society and the forestry sector.

In connection to the NFI, experiments involving measuring stumps from felled trees and "reconstructing" trees by using information from sample trees, seemed to be a successful method in order to produce such an annual statistics. One advantage in using this method was that the removals were obtained as "trees" and not as "trading assortments" (sawlogs, pulp wood, chips, etc.), and that the volume was presented in the same unit of measurement as the volume of growing stand. Furthermore, information concerning the location of the removals, and the type of forest, etc., could be determined.

A condition required before the stump inventory could provide annual records, however, was that the surveying methods should be transformed from covering a couple of counties a year to providing a nationwide annual coverage. A governmental decree was issued in 1952 that such a rearrangement should take place, whereby the final phase of the second NFI was hastened and the planning of the third NFI 1953–1962 was initiated together with an extensive investigation.

The strip design, used earlier, was transformed into a system of square survey tracts, and circular sample plots were laid out along side these squares. The inventory on each tract occupies one day's work for a team of field-workers. Annually 1/15 of the number of tracts in northern Sweden and 1/10 of the number of tracts in the rest of the country were to be subjected to inventory. After a couple of years, the intensity in the inventory was also raised to 1/10 a year in the northern part, due to funding by the Swedish Forest Service of Sweden among others (approximately 3/4 of the forest land possessed by the State is situated in the two northernmost counties).

A major advantage with the new system was that one could easily add new observational or measuring procedures to the survey and, after a period of one year's field work, obtain a sample for the entire country. The accuracy of the data could therefore be enhanced continually by repetitions. One example of this is the inventory of the road network carried out by the NFI during the years 1957–1963. Floating of timber was then on the point of discontinuing and about to be replaced by lorry transport, and the issues concerning the length and qualities of the network of forest roads were of vital importance. Another advantage was the possibility of successively presenting results in the shape of moving averages. One disadvantage with the new survey system compared to the old one was that it now became more complicated to consider the specific conditions within the various counties.

The fourth NFI 1963–1972 was conducted with the same aims and ideas as the preceding survey. The intensity rate by which the forest survey was performed, however, proved to be the same throughout the country, viz. 1/10 of the number of inventory tracts.

During this period questions were raised regarding the long-term productive capacity of the forest soil and its dependence on the soil scarification methods used in the mechanized forestry. In addition, the condition of the terrain concerning its carrying capacity and off-road mobility for engines, had to be examined. Researchers dealing with wildlife management were interested in the access and the utilization rate of game fodder in different parts of the country and forests, mainly with regard to cervid, but also for reindeer. When suitable description and sampling methods had been developed, the survey crew were provided with an additional person, financed by specific projects, for these three aspects of the survey.

The preparations for the fifth forest survey 1973–1982 were performed at a time when the ambitions to plan in society had been fully established. The physical community planning was supposed to be carried out from an ecologically rational perspective. Various decisions about land-use were to be tested in ecological "total models". In this context it was suggested that the NFI indeed could constitute a significant part of a recurring natural resource inventory.

A general aim for the NFI was formulated as follows:
The NFI should provide a successive basis for planning and monitoring of the utilization of forest as a natural resource at the regional as well as at the national level. Furthermore, the NFI should provide information on the utilization of types of land other than forest land, with the exception of land in urban areas, and agricultural land in only a restricted sense. The report should concentrate on current state, actions taken together with further changes occurring.

With this background in mind, i.e. to be able to improve observations concerning actions taken and other changes, we put forward a proposal indicating that permanent sample plots should be introduced in the NFI. Similar experiments in the beginning of the 1970's had given valuable experience in establishing and re-surveying such sample plots. When looking at this with the benefit of hindsight, I have to admit that it was for our own good that we did not receive any funding for the laying-out of permanent sample plots. The registration- and computer techniques were not yet developed sufficiently, and perhaps, we lacked the mathematical-statistical maturity to be able to utilize the possibilities that the permanent sample plots would provide. Bearing these cicumstances in mind, there might have been a considerable risk that we would not have succeeded too well and that the method would become disreputable.

During the period 1973–1982 the forest survey was conducted in a similar way to the two from 1953 and onwards. There was, however, an effort to strenghten the felling statistics by intensifying the stump inventory by using a network of specific "stump inventory tracts." The project was not particularly successful and was abandoned after a few years.

The long-term productive capacity of the forest soil had become an issue of high priority. The soil survey that earlier had been carried out as an experiment was now a part of the basic inventory phases in connection with the field work.

When the sixth NFI was planned, i.e. the one now in progress, the preparations were conducted as a developing project provided by specific project means.

In a questionnaire, among other inquiries, the following conditions were said to be taken into consideration in the design of the survey:

- The demand for timber was considered to extend the supply within the near future, so that if more timber were available, the industry would expand its capacity. The timber balance would then become vulnerable. Consequently, the state of the forest and felling had to be scrutinized closely, and it was of crucial importance that changes were registered. There is also an increasing demand for high-quality consequence calculations on the extent of possible future felling.
- Changes of various kinds in the environment may occur with increasing rapidity and cause enhanced damage. One example is the increase in the emmission of acid and nitrogen compounds. The survey methods should be developed so that by using them one

can easily discover changes that can effect, for instance, the long-term productivity of the forest soil.

- New problems and aspects regarding the utilization of the forest are constantly arising; for instance damage of young pine stands caused by moose, the role of forestry in the context of energy issues and a possible future wood-based chemical industry. A more complete utilization of the wood biomass can be expected.
- Participants outside the forestry are expected to make increasing demands on the forest resources, which implies both measurable characteristics of the forest as well as more abstract values such as the features of the landscape, variation, the existence of certain types of nature, etc.

Bearing this in mind, the following changes were made:

- The forest survey was designed to keep up with changes in a better way than before, principally by introducing permanent sample plots.
- The impact of man on the state of the forest, mainly by felling and actions of regeneration, was given more attention.
- New variables replaced some old ones in order to better reflect current and future concerns in the forestry.
- The intensity of the forest survey was increased on land in which it could become a reality that land-use was transformed into forestry, principally mire and uncultivated pasture.
- The collection of data concerning the site was intensified by a specific site classification of the permanent sample plots.

The changes were not supposed to cause a reduction of the precision in the classification of the volume of growing stand. Neither should the continuity of significant variables be upset, and the instructions were to follow-up, for instance, the development of the volume of growing stand over extended periods of time. The possibility to co-ordinate the NFI with other surveys should be taken into consideration, principally the programmes issued by the Swedish Environmental Protection Agency for national environmental monitoring (the National Environmental Monitoring Programme, PMK) and the general forest survey (ÖSI) conducted by the National Board of Forestry.

As a basis for the statistical design of the forest survey mathematical-statistical investigations were used, for instance, topographical variation within different areas, the importance of the size of the sample plot together with information about the use of time in connection with various phases in the survey and, of course, the economic reality in the shape of available resources.

Principally, the term "statistical design" embraces:

- the dividing of the country into regions (strata with uniform samples; 5 regions)
- the designing of the survey tracts (squares with a side-length from 1,800 metres in the north to 300 metres in the south)
- the weighing between permanent and temporary survey tracts (the same amount of permanent and temporary survey tracts, i. e. approximately 850 per year; 8 sample plots for each permanent tract and 12 for each temporary tract)
- the size of the sample plot (10 and 7 metres radius, respectively, for each permanent and temporary sample plot for measurements; 20 metres radius in special cases).

The permanent tracts were laid out during the five-year period 1983–1987 in order to be re-surveyed for the first time during the period 1988–1992 – at the same time as an equal number of temporary tracts were surveyed each year.

To be included under the heading "statistical design" should also be the mathematical method which is supposed to utilize data in an optimal way both from permanent as well as from temporary sample plots and from various surveys, by using different calculation methods of, e.g., volume of growing stand per ha.

In this survey, aerial photographs have been introduced and put into general practice by the NFI, during the first year as stereoscopic pairs and later as single images. They are, however, used only as a complement to the standard map and the determination of the location of the sample plot in connection to the size of stands, etc.

Urgent reports concerning the so-called new forest damage, caused the introduction of an analysis of defoliation of conifers, later extended to include birch. These analyses are now a part of a program of European co-operation designed to monitor damage to forests.

At the moment, in August 1992, the field work constitutes the final phase of the last year of the sixth NFI. Simultaneously, we are eagerly awaiting the proposal from the forestry committee appointed by the Government, due to be announced on the 1st of September. Being an important phase in the evaluation and supervision of the forestry policy, it will decide on the future size and financing of the NFI.

As a basis for its resolution, the forest committee has received a proposal made by us concerning the NFI 1993–2002, the seventh forest survey. This proposal has been approved by the Board of the Swedish University of Agricultural Sciences and of the National Board of Forestry.

In the memorandum we state that the survey carried out by the NFI is nationwide and relies on solid statistical design using objective sampling. It is long-range and provides for continuity in making measurements and assessments. The data collected are position-determined and allow for co-ordination with other similar data. New data can be collected at low marginal cost. Finally, the existing organization which conducts the NFI is effective and its staff experienced.

The proposal is based on overall demands for the survey to present data about forest conditions for smaller geographic areas than has hitherto been possible, and for better environmental monitoring throughout the country. The NFI can play an important role when it comes to obtaining better information about the health of the forests – their vitality and damages – as well as about various environmental conditions beyond those concerned purely with forestry, such as conditions in the national parks, reserves, and in the high mountains.

Remote sensing techniques within forestry are developing rapidly, and we have now reached the point where it may be feasible to incorporate satellite data into the NFI. These techniques contain a great potential for improving the survey. They cannot, however, lessen noticeably the need for field surveying if the level of ambition is to be maintained as concerns, e.g., data at the regional level.

One significant advantage of introducing remote sensing is that current data related to ground-acquired forest measurements can be obtained for areas of variable size and then used as a basis for local management planning. As the information is based on objective methods, the error associated with forest or environmental parameter estimates can be estimated in a scientifically valid way.

Therefore, prior to the start of the new ten-year period in 1993:

- Permanent sample plots should also be established in national parks, reserves, and high-mountain areas.
- Forest site survey should be performed on a rolling basis in order to obtain shorter observation/sampling intervals for variables with a rapid rate of change.
- Work on development of methods for the use of remote sensing techniques in surveying should be intensified. The work should aim at an operational introduction of the technique by 1998, when the second five year stage of the period begins.
- Staff resources for data collection, processing and analysis should be strengthened.

The memorandum presents the resource needs of the NFI at an unchanged level of ambition and at suggested increases in that level.

Key words for the future NFI will be:

- Objectivity
- Quality
- Topicality
- Flexibility
- Efficiency.

REFERENCES

Anon., 1914: Värmlands läns skogar jämte plan till en taxering av Sveriges samt-liga skogar. Av Kommissionen för försökstaxering i Värmlands län. Stockholm, 227+147 p. Anon., 1932: Uppskattning av Sveriges skogstillgångar verkställd åren 1923–1929. Av Riksskogstaxeringsnämnden. *Swedish official reports series,* 1932:26. Stockholm, 255+215 p.

Anon., 1947: Vid andra riksskogstaxeringen av Norrland åren 1938-42 använd metodik och härom vunna erfarenheter. Av 1937 års riksskogstaxerings *Swedish official reports series* -nämnd. , 1947:36. Stockholm, 205 p.

Näslund, M., 1986: Riksskogstaxering och avverkningsstatistik 1937–1953. *Kungl. Skogs- och lantbruksakademiens tidskrift*, vol. 125, no. 4–5, pp. 213–235.

Hagberg, E., 1955: Den nya riksskogstaxeringen. *Industriens upplysningstjänst*, 1955:3, pp. 109–121.

Anon., 1973: Mål och metoder för ny riksskogstaxering m.m. Symposier på Skogshögskolan den 27 och 28 november 1972. Del 1 o. 2. *Royal College of Forestry, Dept. of Forest Survey, Research Notes*, no. 16, 99+193 p.

Lundmark, J-E., 1974: Ståndortsegenskaperna som bonitetsindikatorer i bestånd med tall och gran. (Summary: Use of site properties for assessing site index in stands of Scots pine and Norway spruce.) *Royal College of Forestry, Dept. of Forest Ecology and Forest Soils, Research Notes*, no. 16, 298 p.

Ranneby, B., Cruse, T., Hägglund, B., Jonasson, H. and Swärd, J., 1987: Designing a new national forest survey for Sweden. *Studia Forestalia Suecia*, no.177, 29 p.

Kempe, G., 1992: Riksskogstaxeringen 1983–87. Skogstillstånd, tillväxt och av-verkning. (Summary: The Swedish National Forest Inventory 1983–87. State of forests, growth and annual cut.) *Swedish University of Agricultural Sciences, Dept. of Forest Survey, Report 51*, 230 p.

Anon., 1991: The Swedish National Forest Inventory 1993–2002. Proposal memorandum 1991–05–30. By: Swedish University of Agricultural Sciences, Dept. of Forest Survey, 25 p.

THE NATIONAL FOREST INVENTORY OF NORWAY

Stein Michael Tomter
Research Officer
Norwegian Institute of Land Inventory
Aas, Norway

ABSTRACT

This paper gives a historical overview of the Norwegian National Forest Inventory, from the start in 1919 up to the present. During this period, five complete surveys have been carried out, and the sixth one will be finished in 1993.
All the surveys have been based on systematic sampling techniques. The sampling design has, however, changed over the years, and the different methods are briefly discussed.

The National Forest Inventory was established because of the fear of over-exploitation of the forests and shortage of timber in the future. Today, we do not consider that as a real threat to the forests. Standing volume and increment have showed constantly increasing trends since the first inventory. During the past few years, more attention has been directed towards the ecological and environmental aspects of the forests, and this has led to some expansion of the inventory.

Keywords: National forest inventory, sampling techniques, forest resources.

INTRODUCTION

Complaints of over-exploitation of Norwegian forests are known even centuries ago. The fear of lack of wood led to severe restrictions on cutting, the sawmill industry, etc., but also prompted investigations on the relationship between forest drain and increment. The first significant attempt, a description of Norwegian forests, was commenced in 1737. Around the year 1900 the debate concerning the forests' condition was very intense, but nobody was able to verify their conclusions. A proposal to start reliable inventories was accepted by the National Assembly in 1917. Preparations lasted two years, and the first county (Östfold) was surveyed in 1919.

Until 1972 the National Forest Inventory was an independent institution under the Ministry of Agriculture. It was then a part of the Institute of Forest Research for 15 years. Since 1988 the NFI is a sub-division of the Institute of Land Survey, which is responsible for inventory and mapping on all types of land.

EARLIER SURVEYS

The first inventory was carried out from 1919 to 1932, and was nationwide in scope. The design was a strip survey with a strip width of 10 m. Distance between sample strips varied from county to county, in order to reach the desired level of precision. The direction of strips was chosen so that they were mainly perpendicular to valleys. By this means, the risk of errors due to forest periodicity should have been reduced.

The results for area distribution were calculated from the distance of the strips, located on each land class. No tables for establishing site quality classes existed at that time, so a classification into a few groups was performed as a rough estimate. As a complete recording of all trees would have been laborious, trees of certain diameter classes were counted on parts of the strips, according to specific rules. A predetermined number of the trees were sample trees, chosen for more detailed measurements.

The object of the first inventory was mainly the assessment of forest area, standing volume and increment. After the results had been published, the debate calmed down because the values showed no substantial deviations between increment and forest drain. However, the results proved that mean volume was too low, and that yield capacity by no means was made full use of.

The demand for updated results soon emerged. Due to financial problems, the second inventory was not started until 1937. The strip sampling concept was still used for several years. In 1952, a combined strip and sample plot inventory was used. Systematic sample plots replaced the strip sampling in 1954, and tracts were used for the first time in 1956. Each tract consisted of 20 plots separated by 200 m, and the tracts were installed in a grid net with 3 km spacings. The reasons for changing the design was the improvement of methods and gained experiences, combined with improved means of transportation.

New variables were gradually included in the surveys. During the second inventory, for example, site index, development classes, vegetation types, altitude zones, soil conditions and terrain classification were introduced.

The second inventory was completed in 1956, and it was comprised of the counties that were considered to be of greatest forestry importance. Unlike the first survey, results were also published for parts of counties.

The third cycle was conducted from 1957 to 1964. In this survey, the main principles and objectives from earlier were maintained.

With the fourth inventory, the emphasis shifted from an individual county survey into a process, where the whole country was surveyed each year. Each inventory year, recordings were taken on one-twelfth of the total number of sample plots in all districts. After twelve years, results for single counties and even groups of municipalities were published. Because many users of forest data regarded it as desirable to get more updated results for each district, and also due to practical problems, this inventory was discontinued in 1976.

Inventory number five was carried out from 1980 to 1986. As the primary objective at that time was to provide data necessary for national planning, this survey was conducted at a lower intensity than the previous one, and the inventory units were regions consisting of 2–3 counties. Relascope measurements were also used, while earlier, all trees on the sample plots had been enumerated.

CURRENT SURVEY

The sixth inventory began in 1986 and is planned to be finished in 1993. The survey will cover the entire country, except Finnmark, the northernmost county.

Informational needs for forest planning have become more demanding, and public concern about environmental conditions more significant. These are circumstances that have contributed to the design and methods which are used in the current survey. The introduction of permanent plots makes a more careful monitoring of changes over time possible. These plots will also be valuable for growth and yield studies.

Tracts or clusters of plots are applied in this inventory, like the previous ones. The tracts are being installed in a grid net with 3 km spacings covering the country. A half square or L-shape is the basic shape of the clusters, and plots are often separated by 300 m within each tract. The southernmost plot is established as a permanent plot, while the others are temporary.

While the 3 km grid net is fixed, the number of plots and distance between plots within a tract may differ between counties. If the percentage of forest land or the total area of the county is small, the number of plots is increased. This had led to clusters of up to 12 sample plots, while in most districts three plots are used. If the number of plots is high, the shape of the tract is often a complete square rather than a half one, due to practical reasons. In the western part of Norway, the distance between plots is reduced because of difficult terrain conditions.

For inventory planning and orientation to the plots, maps of scale 1:5 000 or 1:10 000 in the economical map series are mainly used. On these maps, boundaries between properties and site quality classes are shown, among other data. Ordinary topographical maps of scale 1:50 000 are utilized in cases when more detailed maps are not available. The inventory is completely based on terrestrial recordings, and at present, no interpretation of aerial photographs or other remote sensing methods are being utilized. However, the institute has started development work on satellite image processing, but it is expected to take several years until remote sensing is an integrated part of the NFI.

The total number of permanent sample plots will be about 11 000, of which 60–70% are located on productive forest land. Totally, more than 30 000 sample plots will be measured during the sixth inventory. Access to the plots is well documented, but highly conspicuous markings are avoided to prevent the plots from being treated in a way deviating from the rest of the forests.

Trees on sample plots are enumerated and diameter is measured, according to certain guidelines:

Sample plots consist of two concentric circles, 100 and 250 sq.m. The smaller plot is used for all trees with a diameter at breast height of at least 5 cm, while the bigger one is applied for trees with a diameter of at least 20 cm.

The selection of sample trees for height measurement, quality assessment, increment boring, etc. is carried out by means of a relascope, factor 6. Increment boring is not performed within the permanent sample plots. However, borings are made near the plots for the assessment of stand age and site index. Variables concerning stand conditions are recorded for a 1 000 sq.m. plot around the centre.

Approximately 50 different stand or area class variables are being measured or estimated for each sample plot. For every sample tree, about 15 variables are being recorded. After initial processing, the data will in addition include a number of variables derived from the original ones.

From the beginning, the aim of the NFI has been an assessment of timber resources. This is still the main objective, but during the last years the survey has been broadened to include more non-wood and environmental aspects. One example is a more detailed system for classifying vegetation types. Another type of information mostly related to environmental concern is the previous land use of spruce plantations in counties with insignificant natural spruce forest. Information on the layer of bushes serving as shelter for animals has been collected for the last two years. Data such as stand size and the quantity of dead trees are often demanded by others than foresters.

Certain aspects from the Monitoring of Forest Health Program have been integrated into the NFI, for instance, the observation of crown density. The Nationwide Representative Registrations project itself is organized as a separate survey. It has strong connections with the NFI, as it is conducted by the same institute and also makes some use of the same permanent sample plots.

DEVELOPMENT TRENDS

The general trend has been to gather information on more aspects than earlier and to collect more detailed data. This is partly due to the need for information from the community, but also because of improved inventory and data processing methods. At the same time as the range of data is increased, it is also important not to spoil or disturb long time series of key variables. Changes in forest conditions over time have been brought into focus, and a high degree of continuity will be beneficial for this assessment. A conflict between different interests often arises when a change of inventory methods, variables or definitions is considered.

The current survey will be completed in 1993, and the next inventory is scheduled from 1994. Complete plans for this inventory are not yet prepared, but our preliminary scheme includes the extension of the inventory to comprise other types of land as well. The institute is responsible for collecting land information in general, and the aim is to turn the NFI into a comprehensive and nationwide information system for resource and environmental data.

This includes establishing permanent plots on agricultural land, which makes monitoring of changes in area use possible, for instance the amount of agricultural land being changed to forest.

No systematic survey is being performed in national parks and nature reserves today. It could be of great value in the future to be able to compare the state and changes in such areas to those of traditionally managed forests. To be able to give satisfactorily precise results for the protected areas, it may be necessary to intensify the sampling here.

The sub-alpine birch forests have never been surveyed to any substantial extent before. These forests represent rather large areas, on the order of about 30% of the productive forest land in Norway. Sub-alpine birch forests are important both for recreational purposes and as game and non-game habitat. They are also expected to be sensitive to air pollution and climatic changes. Significant reasons therefore exist for starting to monitor these forests.

Finnmark, the northernmost county of Norway, has never been fully surveyed. Most of the area is low-productive, and the coniferous forests are rather scattered. However, results are demanded by local forest administrations, and the information should also be collected for the sake of completeness.

The gathering of information on all types of land will probably be conducted as a continuous inventory, and the entire country covered each year. According to a predetermined pattern, the grid will be made denser every year and after, say 5 years, the total number of permanent sample plots are observed.

In addition to this inventory, where emphasis is given to monitoring changes, there also seems to be a need for a survey providing updated information at the county level. The principles will be similar to those of the current inventory, but the inventory cycle will be somewhat longer, for instance 15 years.

One of the regular applications for each surveyed county or region has been long-term forecasts of potential cutting. There seems to be a need for models allowing for more flexible forest treatment, and development work on this topic is going on. In particular, the aim is to make the data models more suitable for sub-alpine forests, for which clear-cutting cannot be assumed. A system for assessment of timber quality already exists in the NFI. However, a more objective system for describing quality is desirable, especially as a basis for future projections.

INVENTORY RESULTS AND ASPECTS OF THEIR PRESENTATION

The Norwegian National Forest Inventory was established at a time of considerable uncertainty about the future of the forests. The results have later contributed to our view that over-exploitation and shortage of timber is no longer a real threat. Today, other kinds of risks have been brought into focus.

Growing stock has steadily increased since the first inventory. In the twenties, the volume under bark was a little more than 300 mill. cu.m. Today, the same quantity amounts to 550 mill. cu.m. Similarly, the annual increment increased from 10.7 mill. cu.m. to 19.5 mill. cu.m. during the years of inventory. These tendencies can be explained by interpreting the number of trees in different diameter classes. In particular, the number of trees with a d.b.h. over 30 cm has increased substantially, as it has more than tripled. Productive forest area has remained rather constant during the period, though some districts recently have shown an increasing trend.

The survey results are primarily a tool for strategic planning by central authorities. One of the most important users is the Ministry of Agriculture. Even since the first inventory, laws and regulations are formulated partly as a result of information from the NFI. Forest authorities at the county level will mainly use survey results as guidelines for control and coordination of activities within their field of responsibility. A reasonable management of forest resources is the aim of the forest owners' associations, and survey results are of substantial value for their work. Other groups of users are forest industries, researchers, educational institutions and also organizations and authorities dealing with environmental issues.

The most important product from the NFI has until now been printed reports for each county, containing a rather comprehensive section of tables. Summaries of results for the entire country have also been published. A not insignificant part of the results are provided to the users directly on request.

Reporting for international forest resource and environmental data assessments should also be mentioned. One of the problems we face in this context is the fact that the inventory cycles have always comprised the area below the coniferous forest limit. Parts of the sub-alpine birch forests should undoubtedly be regarded as forest, according to the definitions. As yet, some of these data have to be determined by rough estimates. There may also be a lack of harmonization as regards distinction between productive forest area and other forest land below the coniferous forest limit.

It is conceivable that there will always be a limit for the degree of cooperation and harmonization of inventories in different countries. This is due to both traditions and natural conditions. However, knowledge of other systems and regular contacts across the borders will contribute to improvement of compatibility.

REFERENCES

Landsskogtakseringen, 1968: The National Forest Survey of Norway. Instructions for field work. Landsskogtakseringen, Oslo. 16 p.

Landsskogtakseringen, 1970: Taksering av Norges skoger. Landsskogtakseringen 50 år 1919–1969. Landsskogtakseringen, Oslo. 210 p.

Løvseth, T., 1987: National report: Norway. Ad hoc FAO/ECE/ FINNIDA meeting of experts on forest resource assessment. *Bulletins of The Finnish Forest Research Institute* 284, pp. 245–249.

Tomter, S. M., 1990: The National Forest Survey of Norway – Some notes about sampling design and data processing. Forest Inventories in Europe with Special Reference to Statistical Methods. Proceedings of the International IUFRO S. 4.02 and S. 6.04 Symposium, May 14–16. 1990, Birmensdorf, Switzerland, pp. 66–69.

MULTI-SOURCE NATIONAL FOREST INVENTORY OF FINLAND

Erkki Tomppo
Professor of Forest Inventory
The Finnish Forest Research Institute
Helsinki, Finland

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 eight inventory, in order to obtain geographically localized, up-to-date information and for areas smaller than earlier. Sampling design and sample plot measurements have been changed to some extent. A number of the sample plots have been made permanent. The method exploits satellite image data, 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 so 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 8 million hectares, producing theme maps and statistics for large and small areas (even single stands). The results have been compared with the estimates of a standwise forest inventory and, for large areas, with estimates based on field sample plots of the National forest inventory. The results match quite well indicating the applicability of small area estimates.

Keywords: National forest inventory, forest resources, satellite images.

INTRODUCTION

The information of the Finnish National Forest Inventories (NFI) has been utilized in large area forest management planning, in making decisions concerning forest industry investments and as a basis for forest income taxation. Another inventory system, a standwise forest inventory, has been used for small scale inventories and for operational forest management planning. These inventories are carried out by ownership groups: Forestry Boards for private forests (63 % of the forest area), National Board of Forestry for state owned forests (24 % of the area), and by ownersselfs for other forests. NFI covers all forests and the information has been used by all ownership groups for justifying and calibrating their own results.

The sampling system of the First National Inventory was linewise survey sampling, introduced by professor Yrjö Ilvessalo (Ilvessalo 1927). The line interval was 16 kilometres for most parts of the country. For reliability calculations, the interval was 13 kilometres in one province and 10 kilometres in Ahvenanmaa. Sample plot measurements were carried out in line strips with a width of 10 metres, with a length of 50 metres at intervals of 2 km. A similar sampling system was employed in the three following inventories.

Detach Γ-shaped tracts have been employed instead of continuous lines since the fifth inventory, the first inventory lead by Professor Kuusela (Kuusela and Salminen 1969). This design is statistically more effective and was also favoured by social developments and 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.

A new feature in the 5th, 6th and 7th inventories was the use of aerial photographs in North Finland (Poso 1972, Poso and Kujala 1971). Two phase stratified sampling (stratification based on aerial photographs) was applied in the 5th and 6th inventories, and photo interpretation plots in the 7th inventory (Mattila 1985). The ground sampling intensity in North Finland has been much lower than in South Finland.

The length of each cycle comprising one complete inventory has been dependent on the funds granted by the State budget, the smallest area unit for which results are required, and the statistical precision of the estimates considered desirable.

The most important administrational unit is the Forestry Board District. These are commonly 0.5–1.0 million ha in area. There are 20 districts. The standard error of the growing stock volume estimate for these districts is between 2 and 4 per cent.

THE NEW INVENTORY SYSTEM

The traditional role of the National Forest Inventory in Finland is to produce objective and up-to-date information of the forest resources and their development for national and regional decision making.

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. The public have also been worried about the environment and the degree of utilization of the forests. The mass media have maintained public fears of wide forest damages. 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.

Because of the low sampling density of the field inventory, reliable results could be computed for fairly large areas only, 150 000 ha and larger. The most recent inventories of the whole country have taken almost 10 years. Further, estimation of changes cannot be properly estimated by temporary sample plots.

To overcome these drawbacks and to get better localized and more up-to-date information, the Forest Research Institute started to develop a new inventory system in 1989. The method exploits satellite image data, digital map data and, in the future, other geographical and meteorological data, for example, in addition to ground measurements and their model-based updating. Satellite images and digital map data have been employed with the sample plots of 8th inventory since 1990.

NewField Sampling System

The new field sampling system has been applied from the summer of 1992, north from the administrative border of North Finland. Some alternatives in sampling design have been tested. The sampling unit is still a cluster, called a tract. The distance between two tracts is 7 kilometres both in north-south and east-west directions. One tract has 15 sample plots, of which three are permanent and the other twelve temporary. The coordinates of the trees on permanent plots are registered in order to identify the trees during the next inventory. The new sampling design is shown in Figure 1, Appendix 1.

Satellite image based digital volume maps and sampling simulations were employed in designing the final sampling system. With each design, 1000 samples were chosen and standard deviations of mean volume computed, (Henttonen 1992). This stood for the standard error of mean volume. It was found that the amount of plots per cluster must not been over 15. A quite important aspect was also the fact that a sampling unit (cluster) should be, on average, one day's work.

It was found that the 'optimum' design depends on the distrubution (amount) of forest land and the heterogeneity of forests, for instance, and therefore varies from south to north and east to west. The sampling intensity will be fitted to the spatial variation of forests throughout the whole country. The intensity in North Finland will be lower than in South Finland.

The sample plot is still a Bitterlich plot. 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 the area of this summer's inventory (in Kainuu and Pohjois-Pohjanmaa Forestry Board Districts). The maximum radius is 12.45 metres (corresponding to the bh -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, see Figure 1, Appendix 1.

New feature is a small fixed radius sample plot for small trees, i.e. trees not included in the Bitterlich plot. On forest land, those small trees which will remain in the silvicultural regime (and first thinning cutting) are counted.

Satellite Image Data

The most feasible satellite image data are, at this moment, Landsat TM, Spot and MOS-1 images. In the first phase, TM images have been applied and Spot images will also be utilized later. At the moment, the spectral resolution of the TM image is better, while Spot has a better spatial resolution. One TM image covers a larger area than one Spot image making it more likely to yield cloud-free images covering the whole country. According to some previous experiments, the results with TM images are more reliable than those with Spot images due to the better spectral resolution. The use of spaceborn radar data will be tested for updating purposes, e.g. for identifying of clear cuttings.

Digital Map Data

Digital map data produced by the National Board of Survey will be used for improving the accuracy of land classifications and to separate forest and non-forest land from each other, e.g. 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. This information is not yet reliable enough for the country as a whole, so it has been used only for some limited areas.

Agricultural areas and roads have been digitized from base maps having a scale of 1:50,000. At the moment, pure map data have been used for the separation of land classes. A combination of a numerical interpretation and digital map information will be used in the future for classifying agricultural areas, because the map data are not necessarily up-to-date.

Urban area information can be obtained from the housing register provided by the Civil Register of Finland. The coordinates of each house in Finland are known. A digital built-up area mask can be produced from this information.

Water areas could be obtained from base maps but they can be obtained relatively reliably from satellite images.

Some administrative information such as municiple boundaries and, in the future, boundaries of forest holdings will also be used in digital form in order to differentiate computation units.

Digital terrain models are used for correcting original spectral values in order to avoid confusion in image analysis caused by land morphology.

IMAGE INTERPRETATION

The image analysis consists of preprocessing of the image (image rectification, removal of noise, striping, etc.), selection of features, classification, and postprocessing (generalization). The method is chosen in such a way that all inventory variables can be estimated for each pixel. A *k nearest neighbor 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 pixe 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 $w_{(i),p} = \frac{1}{d^2_{(i),p}} \sum_{i=1}^{n} \frac{1}{d^2_{(i),p}}$.

Define the estimate $\hat{m}_p$ of the variable M for the pixel p

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

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 (1991). Both areal statistics of computation units and theme maps with land use information (site fertility, timber assortments and growth by tree species, etc.) have been produced in the classification phase. Regression analysis and discriminant analysis are also possible methods.

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 (1989).

EXAMPLES OF LARGE AREA RESULTS

The above methodology and input data have been applied operationally in estimating NFI -variables in areas of six forestry board districts in South and Central Finland; the total area amounting to 8 million hectares. Sum characteristics of ordinary standwise data, measured for forest management planning purposes, are available as comparison material. These data (referred here as FBD -data) are based on visual ground estimation and information from false colour aerial photographs. One possibility to judge the goodness of estimates is to compare them for large areas with estimates based on field measurements only for which the standard error can be estimated and which are fairly small, e.g. the standard error of the mean growing stock of field inventory in an area of one million hectares is in the order of 1–2 %.

Tables 1–3 show the multisource inventory based estimates (MSI) and the estimates of the field inventory (FI) for some mean characteristics in the forestry board district of Central Finland, with the total area of 1 296 700 hectares.

Table 1. The FI and MSI estimates of mean tree volume by tree species on forest and scrub land, Central Finland, area 1 296 700 hectares.

Tree	FI		MSI	
species	m³	%	m³	%
Pine	42.8	39.6	43.4	40.4
Spruce	48.0	44.4	47.1	43.9
Birch	14.2	13.2	13.9	12.9
Other	3.0	2.8	3.0	2.8
All	108.1	100.0	107.4	100.0

Table 2. The FI and MSI estimates of proportions of timber assortments (%) by tree species on forest and scrub land, Central Finland, area 1 296 700 hectares.

Tree species	Saw wood	Pulp wood	Waste wood
Pine, FI	41.8	52.3	5.8
Pine, MSI	41.6	52.3	6.1
Spruce, FI	55.2	40.9	3.9
Spruce, MSI	55.0	41.2	3.8
Birch, FI	16.1	68.0	15.9
Birch, MSI	15.8	68.2	16.0
Other, FI	5.6	58.7	35.7
Other, MSI	4.5	56.6	38.9
All, FI	43.4	49.5	7.1
All, MSI	43.1	49.5	7.4

Table 3. The FI and MSI estimates of mean tree stem volume increment on forest and scrub land with field inventory (FI), and multi-source inventory (MSI), Central Finland, area 1 296 700 hectares.

Tree	FI		MSI	
species	m^3	%	m^3	%
Pine	2.1	43.8	2.2	44.0
Spruce	1.8	37.5	1.8	36.0
Birch	0.7	13.5	0.7	14.0
Other	0.2	4.2	0.3	6.0
All	4.8	100.0	5.0	100.0

These comparisons show that the large area estimates match quite well. The estimates of the mean tree stem volume as well as timber assortments by tree species are very close to each other with both methods. The small differences in mean tree stem volume is caused by the fact that a part of non-forest land (roads, urban areas) is classified into forests because the digital map data contained some errors.

Another possibility for judging the goodness of estimates is to compare them with characteristics of standwise data, measured for forest management planning purposes. These inventories are carried out in Finland separately for private, government and company owned forests. They are based on visual ground estimation and information from false colour aerial photographs and therefore involve some subjective errors causing problems in comparisons. These results confirm the applicability of the MSI method at communal level, see Tomppo and Katila (1991).

Comparisons have also been carried out with the estimates of small scale inventories. These, and the large area results, as well as tests, show that the satellite image-aided inventory method works fairly well at the communal level. The results are promising and the satellite image-aided NFI method has made or is expected to facilitate the following benefits:

1) to be able to estimate all the variables of the national forest survey for each point of the country. The variables include the properties of site type, soil, growing stock, mortality, cutting, and damages and diseases. It is anticipated that some improvement in estimates of all variables can be expected compared with the current situation. Estimates of variables concerning a single pixel may remain unreliable. However, communal level estimates, and in the case of some variables possibly forest holding and stand estimates, are applicable.
2) The cost/benefit -ratio of the inventory can be improved, and the rotation can be shortened in the future. The information given by the inventory can be improved considerably with little additional cost. Remote sensing helps the updating of inventory data.

Clouds prevent the acquisition of imagery which covers the whole country each year. This is possible every third or fifth year, however. The field data can be updated with a slight change detection (removed trees can be identified) in permanent sample plots and tree and stand models, and simulation between two image acquisition dates.

3) The geographically localized information can be stored in digital form and be transfered easily into the users' databases for further processing.
4) Changes, e.g. growth and mortality, will be more accurately estimated than before. The new ground sampling design, which includes permanent sample plots, will support this task.
5) Monitoring forest health and diseases will be more effective than before.
6) The NFI-method will serve as a sampling frame for other studies. Forest health researchers can, for instance, direct their studies to such forests where something alarming has been detected.
7) Inventory of multi-use resources will be more effective. Examples are reindeer rangeland inventory in North Finland.
8) Finally, the NFI will serve as a GIS, combining of multi-source information and map production are possible.

There exist some difficulties in using remote sensing technique of optical area. Sometimes, clouds prevent obtaining imagery of the inventory area for the same growing season in which the field measurements were carried out. The quality of images of recent natural resource satellites are not good enough for small scale (standwise) inventories. Both the spatial and spectral resolutions have to be improved for those purposes. Striping and noise are also fairly high. Moreover, confusions occur in estimates if the number of boundary pixels (mixed pixels) is high.

In the near future, other remote sensing data, such as radar data, will be tested for detecting, e.g. clear cutting areas.Different kinds of airborne data can be utilized later.

DEVELOPMENT OF FINNISH FOREST RESOURCES

The forest resources of Finland were fairly stable from the early 1920s until the 1970s. The total growing stock varied between 1500 and 1600 million m^3, in spite of the 10 % loss of forest area after the Second World War.

The effects of intensified forest management and silviculture started to take effect at the end of the 1960s in the form of greater growth and volume of the growing stock. This trend has continued to the present day. The updated estimate of growing stock (1990) is 1,880 million m^3. The annual growth estimate for the period 1985–89 was 79 million m^3. During the 1990s, the growing stock is expected to exceed 2000 million m^3.

The proportions of three main tree species pine, spruce and birch has also been fairly constant; with pine 45 % and spruce 37 % of the growing stock in 1990.

The land areas, growing stock and growth by tree species in 1st, 3rd and 7th inventories are given in Tables 4 and 5. The updated figures corresponding to the situation in 1990 are given in Table 5.

The increase of forest land area is mainly a result of the drainage of peatlands. This has also increased the total growing stock.

Table 4. Land areas (1000 ha and %) in 1st, 3rd and 7th

	1st 1922–24	3rd 1951–53	7th 1977–84
Forest land	20138 (58.6)	17352 (56.2)	20065 (65.9)
Other wooded land	5125 (14.9)	4522 (14.8)	3157 (10.4)
Waste land	5033 (14.7)	4441 (14.6)	3152 (10.3)
Other land	4064 (11.8)	4225 (13.8)	4091 (13.4)
Total	34360 (100)	30540 (100)	30464 (100)

Table 5. Total growing stock and growth (million m^3) by main tree species in 1st, 3rd and 7th inventories and updated figures in 1.1.1990.

	Volume			
	1st 1922–24	3rd 1951–53	7th 1977–84	1990
Pine	777	672	746	850
Spruce	481	549	613	690
Decidious	330	317	302	340
Total	1588	1538	1660	1880
	Growth per annum			
	1st 1922–24	3rd 1951–53	7th 1977–84	1985–89
Pine	25	22	27	34
Spruce	16	20	25	28
Decidious	14	13	16	17
Total	55	55	68	79

The standard errors of these figures (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 growth 1.0 %. The corresponding figures for a typical computation unit (1.2 million ha) are 1 %, 2 % and 3 %.

CONCLUSIONS

Established over 70 years ago, the Finnish National Forest Inventory produces time series of forest resources on the regional and national levels. The information has given a firm foundation for planning Finland's forest industries and the utilization and management of the forests.

The inventory method is now changing from the repeated temporary field inventories to an up-to-date, multi-source forest resource monitoring and forest management planning system. In addition to the traditional publications, the inventory results will be supplied as thematic maps and in digital form for further processing. The field sample of the NFI will serve as a general forest sampling framework for forest research. The utilization of the inventory results is creating new co-operation between practical forestry and forest research.

REFERENCES

Ilvessalo, Y. 1927. The Forests of Suomi (Finland). Results of the general survey of the forests of the country carried out during the years 1921–1924. Communicationes Ex Instituto Quaestionum Forestalium Finlandiae. Editae 11.

Henttonen, H. M. 1992. Planning of sampling design of National Forest Inventory by means of satellite image based growing stock map. Manuscript, 5p.

Kuusela, K. and Salminen, S. 1969. The 5th National Forest Inventory in Finland. General design, instructions for field work and data processing. Commun. Inst. For. Fenn. 69.4.1–72.

Kuusela, K.and Salminen S. 1991. Suomen metsävarat 1977–1984 ja niiden kehittyminen 1952–1980 (in Finnish). English summary: Forest resources of Finland in 1977–1984 and their development in 1952–1980. To appear in Acta Forestalia Fennica.

Mattila, E. 1985. The combined use of systematic field and photo samples in a large-scale forest inventory in North Finland. Seloste: Systemaattisen ilmakuva- ja maastonäytteen yhteiskäyttö laajan metsäalueen inventoinnissa Pohjois-Suomessa. Commun. Inst. For. Fenn. 131:1–97

Poso, S. 1972. A method for combining photo and field samples in forest inventory. Seloste: Ilmakuva ja maasto-otokseen perustuva metsän inventointimentelmä. Commun. Inst. For. Fenn. 76(1):1–133.

Poso, s. and Kujala, M. 1971. Ryhmitetty ilmakuva- ja maasto-otanta Inarin, Utsjoen ja Enontekiön metsien inventoinnissa. Summary: A two-phase forest inventory method based on photo and field plot sampling as applied in northernmost Lapland. Folia For. 132:1–40.

Tomppo, E. 1989. Comparisons of some classification methods in satellite image aided forest tax class estimation. In: SCIA '89 Proceedings of The 6th Scandinavian Conference on Image Analysis. Oulu, Finland, June 19–22, 1989. Vol 1. 150–157.

Tomppo, E. 1991. Satellite Image-Based National National Forest Inventory of Finland. In: Proceedings of the symposium on Global and Environmental Monitoring, Techniques and Impacts, September 17–21, 1990 Victoria, British Columbia Canada. International Archives of Photogrammetry and Remote Sensing, Vol 28, Part 7–1, pp. 419–424.

Tomppo, E. and Katila, M. 1991. Satellite Image-Based National National Forest Inventory of Finland. In: Proceedings of IGARSS'91, Remote Sensing: Global Monitoring for Earth Management. 1991 International Geoscience and Remote Sensing Symposium. Helsinki University of Technology, Espoo, Finland, June 3–6, 1991. IEEE Catalog Number 91CH2971–0. Vol. III. 1141–1144.

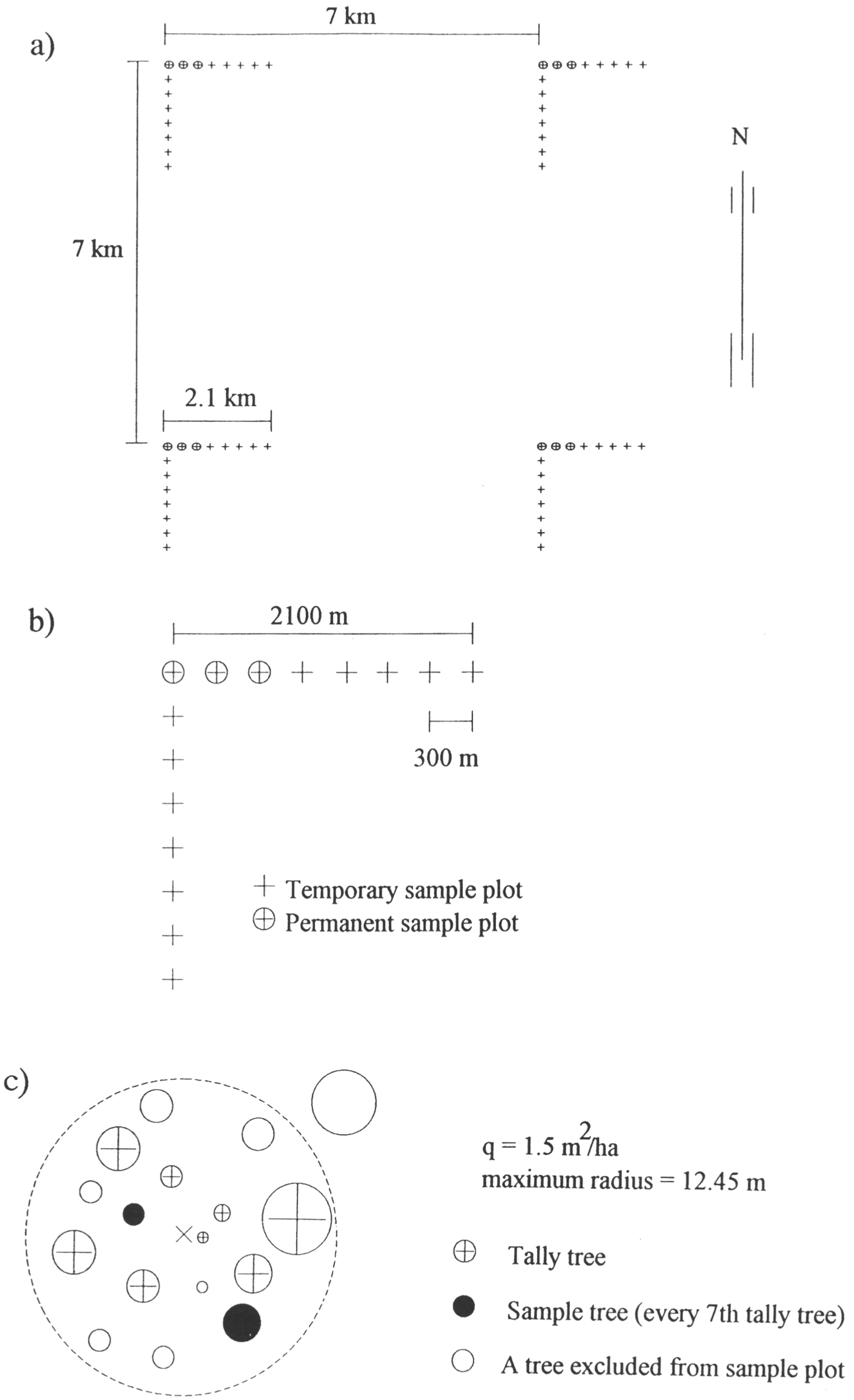


Figure 1. The sampling design of the 8th National Forest Inventory in Kainuu and Pohjois-Pohjanmaa Forestry Board Districts, a) locations of clusters, b) location of sample plots on a cluster and c) a restricted sample plot.

SAMPLING DESIGN AND DATA ANALYSIS OF THE SECOND SWISS NATIONAL FOREST INVENTORY

Rüdiger Jensen & Michael Köhl
Swiss Federal Institute for Forest, Snow, and Landscape Research
Dept. NFI
Birmensdorf, Switzerland

ABSTRACT

The first Swiss national forest inventory (NFI) was conducted as a systematic survey on a 1x1 km grid, and since the aim from the start was to establish a permanent inventory system, all 10675 accessible plots were permanently marked. Aerial photography was used in the first Swiss NFI for the estimation of forest area.

The 2nd NFI will be a combined inventory, using terrestrial assessments as well as aerial photographs. Two-phase sampling for stratification will be integrated into sampling with partial replacement (SPR).

The emphasis of this paper is on the statistical design and the estimation procedures. The data flow and the integration of the photo interpretation data into data-base system and the analysis software will be presented.

THE FIRST SWISS NFI

The first Swiss NFI was conducted between 1983 and 1985. The final results were published in 1988 (EAFV, 1988). The objective of the first NFI was to determine the condition of forests in Switzerland on a large-scale basis so as to furnish a basis for decision-making in forest policy. The main emphasis was on the collection of data concerning standing volume, forest area, assortments and quality of timber, site characteristics, and accessibility. The units of reference were in addition to all Switzerland, the five productive regions Jura, plateau region, lower Alps, Alps, and southern slopes of the Alps.

Aerial photography (b/w, 1:25000), topographic maps, field samples and questionnaires circulated among the local forest services were utilized as data sources. A 1x1 km grid was laid out over the entire country, and apart from those areas occupied by water or above the timberline, all intersection points were evaluated on aerial photographs with an analytical plotter. The forested area was determined by aerial photographs. Some 11000 point were classified as forest and terrestrially surveyed. All terrestrial samples were permanently marked.

The terrestrial sampling unit comprises not only two concentric plots but also an interpretation area of 50x50m. On the latter, data on area and stand conditions were recorded. On the smaller circular plots, with an area of 0.02ha, all trees with a diameter at breast height (DBH) over 12cm, and on the larger plots, with an area of 0.05ha, all those with a DBH above 35cm were registered. Some trees on the plot were selected as tariff trees. For those trees, both the height and the diameter at 7m were also determined. For the tariff trees the volume was calculated by volume functions with the DBH, the height, and the diameter at 7m as independent variables. With the single tree volumes of the tariff trees volume tariffs of the form v=f(DBH) were derived. Those volume tariffs were used for the volume calculation of the non-tariff trees.

The data analysis system of the first NFI was based on a file system and specially developed, batchoriented routines (Brasse, 1 1988). Special conversion programs were available for data extraction, data export and data import. The entire NFI software was written in FORTRAN and was made up of 23 main programs with 250 subroutines and 15000 statements. The most important program was that for table evaluation. Thirty different types of tables could be derived.

PROPOSED SAMPLING DESIGN

The proposed sampling design has two main features: first, double sampling for stratification will allow the more efficient use of aerial photography. Secondly, ground observations will be conducted on permanent and new plots (Köhl, 1992).

Photo-Interpretation Phase

In the second NFI the application of aerial photography is to be extended. Poor accessibility and difficult terrain in the Alps and on their southern slopes render terrestrial surveys costly, so that aerial photography offers an attractive alternative especially in these regions. Black-and-white photographs at a scale of 1:25000 can be obtained from the Federal Office of Topography, which conducts aerial surveys of the entire country on-a six year rotation. The dates and scales of the aerial photographs are fixed and must be taken as pre-set conditions in a combined, two-phase inventory.

The photo interpretation will be done using two analytical plotters. With the exception of water areas and altitudes above the timberline (i.e. 2500m a.s.l.) all sample points are investigated on aerial photographs. The sample plots are classified into the categories forest, brush forest, and non-forest. On forested plots reference points that are clearly definable on the photo as well as in the field are selected. The reference points are used by the field crews to locate the plot centers.

Much emphasis will be put on the stratification of the photo plots. Several stratifying variables have been found to be useful for stratification. Those are stage of forest development, forest type, mixture proportion, stand structure, and stand density. In addition to the stratification according to one of these variables, a disturbance stratum will be identified on the photos. By the definition of a disturbance stratum the estimation of change will be more efficient as the variation within the strata will be decreased. A plot harvested between the first and second occasion will be placed in the disturbance stratum. An undisturbed plot could grow to an adjacent stratum.

As the stratum weights used for further calculations are based on the photo stratification all photo plots – new and matched ones – have to be stratified. New photo plots will be transferred to old aerial photographs to detect any disturbances. Old photo plots have to be transferred to new aerial photographs. The results of the field assessments of the first NFI can be used for the disturbance detection in matched photo plots at the second occasion. When interpreting the matched photo plots on new aerial photographs, the results of the first NFI will be presented to the interpreter by a stereo superimposition system. Together with verification on the old aerial photographs the photo plots will be classified to strata.

Especially in the Alps changes in land-use are very likely to occur, as meadows and agricultural land are abandoned and forest grow into those areas. Therefore the interpretation of photo plots will start with the classification to land use classes (non-forest, brush-wood forest, and forest. In land-use classes non-forest and brush-forest no further interpretation will be done. On forested plots, the identification of disturbances will follow. If no disturbances have occurred, a further stratification to forest strata will be carried out.

About one third of the NFI plots are located at a forest border. Therefore the plot centers have to be carefully relocated on aerial photographs. Since the orientation of aerial photographs is subject to errors, the transfer of photo plot centers from old to new aerial photographs can not be based purely on the plot coordinates. The reference points of the old plots will be used for the correction of errors in the orientation and the relocation of plot centers.

Ground Assessments

The ground plots or second-phase samples are a subsample of the first-phase photo samples within each stratum. As regards permanent inventories, there are certain objections to an allocation other than proportional in stratified sampling:

- it is uncertain whether the strata will remain constant over the course of time;
- the variables of interest are subject to change;
- the integration of cantonal forest surveys with an increased sampling intensity is more complicated;
- the flexibility of the design for sampling on successive occasion is limited;

Thus, proportional allocation will be applied and the allocation of ground plots in the strata will be in direct proportion to stratum weights, although in multi-resource inventories proportional allocation may be inefficient for some variables.

In analyzing the error components of the first NFI it was found that the survey design of the Swiss NFI is sensitive to bias (Gertner and Köhl, 1992). most of the bias can be assigned to the volume estimation. Therefore the volume estimation methods will be revised.

The need for information on non-productive forest functions requires additional terrestrial assesments. A soil survey and a vegetation survey will be conducted on a sub-sample of the NFI ground plots. The annual forest health monitoring will be continued on some 700 NFI plots. The assesments of needle-leaf loss as the most important indicator of tree vitality according to the ECE-standards will be retained. The protective function will be assessed on both ground plots and aerial photographs and is the subject of a special investigation.

Estimation Procedures

In SPR all three types of plots – new, old and matched – are used for the estimation of current values and change. In order to avoid the problems encountered with SPR, only new and remeasured plots will be used for the estimation of current values. Only remeasured plots will be used for the estimation of change. An update of old, unremeasured plots will not be applied.

Combined ratio estimators (Cochran, 1977) will be applied, which use the stratified mean values or totals of both, an observed attribute and the plot areas. Standard errors of the attribute and the plot areas and the covariance are needed for the calculation of the variance of the combined ratio estimator Double sampling are stratification estimators are applied to calculate the variance of the mean of the attribute, the variance of the mean of the plot areas, and the covariance term. Total values are given by the combined ratio estimates and the area estimates obtained from aerial photo interpretation. Since the number of sample plots is different for the estimation of change and the estimation of current values two plot expansion factors need to be applied for the remeasured plots

The result will be derived for the five productive regions, which are smallest preset unit of reference. The results for whole Switzerland are given by the combination of the productive regions.

These estimation procedures are less efficient than the SPR estimation procedures. However, the disadvantage of reduced efficiency in comparison with SPR is compensated by the simplicity of the proposed estimation procedures. No regression estimates and no adjustment for tables is necessary, which facilitates analysis. The use of data base management system is much more practical with the simplified estimators than with SPR-estimators. The results of the inventory data will be more reliable and intuitively easier to understand.

DATA ASSESSMENT AND ANALYSIS

In the following the software implementation of the data analysis system for the second NFI is presented. Aspects of data management, data preparation and data processing are treated. Nowadays it is certainly not appropriate to build a data analysis system for data management and processing with 3rd generation language (3.GL) tools only. On the contrary an open concept has to be implemented. This concept is open for program changes, easy to document and uses standard solutions for data management and processing.

Tools

The data analysis is definitely separated from the data preparation. The data management language structured query language (SQL), and the statistical analysis package SAS, SAS Inst. Inc., Cary, NC, USA, are the basic tools for the final data analysis system. As a side effect of these standards for data base management and statistical analysis (SAS and ORACLE, Oracle Corporation, USA) a good language documentation is supplied by the program manufacturer. The basic language elements are easy to understand. This gives a well-trained user the ability to easily understand the implemented program code. The use of 3.GL tools implies a big personnel dependence since only a few persons know about the data structure and data analysis procedures. This can be avoided with the use of a data base management system and a commonly used statistical package.

For data management a relational database with the query language SQL and the relational data base management system (RDBMS) ORACLE is USED. The computed variables are upgraded in the data base via SQL or SAS procedures. Some derived variables are very complex in terms of computation and used machine time. In this case 3.GL constructions will be used to optimize the performance of the data analysis system.

Assessment

The data assessment is divided into several components, but the subsequent description is restricted to only two data sources: (1) aerial photography and (2) field surveys. Other data sources such as maps and questionnaires are not taken into consideration.

Aerial Photography

The aerial photographs are interpreted with two analytical plotters (DSR1, DSR15 from LEICA, Leica Ltd. Aarau, Switzerland). Both machines are controlled by a mini computer The manufacturer of the analytical plotter offers a software package for model orientation, for graphical and digital output to a plotting table or to an image superimposition system. With the additional program library the manufacturer offers the possibility to implement new programs. The raw system had to be enhanced for the desired functionality of the hardware.

The software supplied by the hardware manufacturer does not fulfil the needs of a forest inventory. Therefore self-developed software is employed. This software package allows the embedding of the model parameters in a database, the registration of area information and the assessment on single points in the interpretation area. Different parameters for stratification and the forest-/ non forest decision in the aerial photograph are recorded. The forest-/ non forest decision is made by evaluating quantitative and qualitative characteristics such as crown cover and width of a forest single tree height and qualitative observations. As stratifying variables, wood and non-wood functions, and the description of the spatial distribution of trees outside coherent forest areas are assessed. The obtained set of aerial photography data is stored in a data base system. After completion of the aerial photo interpretation in the second NFI this part of the database will contain 600 MByte.

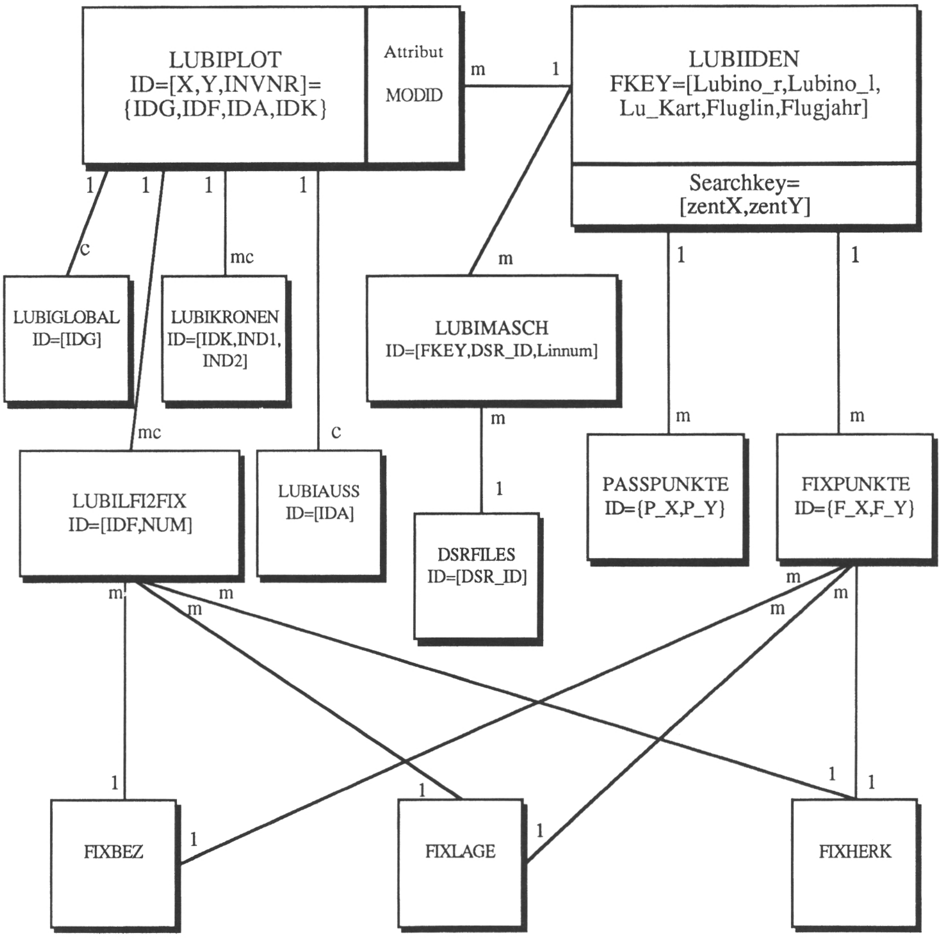


Figure 1: Entity-Relationship diagram of the aerial photography database.

As shown in figure 1 the tables LUBIPLOT and LUBIIDEN are the basic tables. In the table LUBIIDEN an aerial photography pair for a model is identified by the primary key information and a foreign key as reference for identification in other tables. The model data for the analytical plotters is embedded in the database. After model orientation a pair of aerial photographs is ready for interpretation. The data of every registered photo sample is stored in the table LUBIPLOT with a primary key and a foreign key as a reference to other related tables.

Field Surveys

The field crews in the first NFI registered every sample plot with a tally sheet. This data was manually entered into a computer with a data acquisition program and stored in a file system. This procedure had two disadvantages:

(1) a considerable time consumption for the manual coding and (2) a considerable error rate. The data was tested for plausibility and detected errors were corrected. For this reason the data acquisition of the second NFI will be made using a hand held computer with a tally program initially written by the United States Department of Agriculture (USDA) Forest Service (Scott, 1990) This software package will be used and adapted to the special needs of the second NFI.

Data Preparation

The input comprises a set of aerial photo interpretation data and data from the field surveys. Before analyzing data, the logical contradictions of the different data sources must be solved. This means: A rule system must be defined that can solve the logical errors of both data sources. The contradictions are based on different interpretations of the forest-/non forest decision for the following combinations:

(1) right decision on aerial photograph and wrong decision on field survey.
(2) wrong decision of aerial photo interpretation, right decision on field survey.
(3) inaccessible field plots.

The following reasons are possible:

(1) wrong interpretation on the aerial photography or wrong measurements by the field crew.
(2) faulty locating of the sample plot in the field.
(3) wrong location of the sample plot in the first NFI.

In addition to this we have also to deal with real differences that arise through time lags between the taking of the aerial photographs and the survey in the field.

The relations of the data bases for aerial photography and the field surveys for the first and the second NFI are normalized to the second normal form. This facilitates the capability of defining statements with the various kinds of dependencies including the functional, multi-valued join, and inclusion types of dependencies. (Codd 1990, Zehnder 1989).

The settled data is associated with a foreign key and the inventory number (till now first and second NFI). The attributes of the tables are the set of variables for data analysis.

Analysis

A data analysis system can be described as a special data-filter that transforms an input data set into an output data set.

Concept

The concept for the data analysis for the 2nd NFI is oriented towards the design and the implementation concepts for operating systems. Four different types are distinguishable:

(1) Monolithic Systems
(2) Layered Systems
(3) Virtual Machines
(4) Client-Server Model

All structures consist of four main parts: process management, /I/O device management, memory management and file management. These well proved and stable methods will guarantee a transparent and modular structure of the data analysis. (Tannenbaum 1987, Hoare 1972) For several reasons the type (2) as a layered system was chosen for the concept.

Layered System

0	GETENTITY	Process	Definition module for table access, entity description, dynamic allocations
		INPUT	global table description
		OUTPUT	descriptions of entities
1	GETKEYS	Process	associations between different entities, joins
		INPUT	descriptions of entities
		OUTPUT	descriptions of associations
2	GETATTRIBUTES	Process	extraction of the attributes of a table
		INPUT	entity description
		OUTPUT	selected attributes and theta-selects for different tables
3	GETRAWDATA	Process	extract of a subset of data for analysis
		INPUT	entity description, description of associations and selected attributes and theta-selects
		OUTPUT	subset of whole data set
4	MAKESASDATA	Process	preparation of a subset of data in SAS
		INPUT	subset of data
		OUTPUT	SAS data-set
5	PROCESSDATA (1-n)	Process	computation and data display in SAS (several computation options)
		INPUT	SAS data-set
		OUTPUT	table of processed input data
6	COMMUNICATE	Process	user interface communication. Preparation of parameter list of the layers below
7	ANALYZE	Process	user interface:definition of variables for data analysis, output specifications and computation options
		INPUT	user commands via COMMUNICATE
		OUTPUT	table of processed input data

Figure 2: Layered concept for the data analysis

In this layered system different sequential processes are defined. They communicate through a defined software interface. The aim of this proceeding is to achieve independence for the different layers. This guarantees the exchangeability and enlargement of the particular units. The delivery mechanism between the particular processes is done in the following manner:

(7) The 7th layer (ANALYZE) is the visible part for the user and represents the visible part of the data analysis system. This process is the communication interface from the user inquiries to the software system. All user requests, errors' messages from lower layers, computation outputs and system responses are passed through this process.

(6) The definitions of the user requirements for data analysis are passed to the 6th layer (COMMUNICATE) This process examines the requirements syntactically and partially semantically of the users' parameter list Wrong inputs are reported back to the 7th layer. In case of plausible user requirements the parameters are passed to the layers above. This process is the software communication part to the layers above and should not be confounded with the user communication The 6th layer then switches to all layers above and collects run time errors and output messages and reports them back to the 7th layer.

(0) The process in this layer (GETENTITY) passes the actual entity structure of the data base to the subsequent layer. This part allows a dynamic definition of a database. The actual structure of the entity relationship of the database is passed to the other processes every time, when this process is called. In case of changes in the structure of the data base other processes must not be rewritten or adapted to the new database structure.

(1) With the information of the layer below the process (GETKEYS) collects the primary and foreign keys for the next layers. With this information it is possible to construct the necessary theta-joins for data extraction.

(2) The process GETATTRIBUTES extracts the actual defined attributes from the different tables. As layers 0,1 and 2 are declarative these processes collect every time the actual state of the database system. Usually no run time errors in a well-defined data base will occur. The advantage of this data extraction method is, that the user need not know the structure of the database and the database can be dynamically modified in time. The user has the perception of a flat and linear database table.

(3) Starting with the 3rd layer all wrong input combinations and run time errors are reported to the 7th layer. In the process GETRAWDATA the presence of valid variables from the user request is tested. This process compiles the data base query, submits a data extraction query to the RDBMS and prepares a standard output format for the subset of inventory data.

(4) The layer MEKESASDATA processes the formatted data to a standard SAS data set for the next layer. Both processes can use a considerable amount of time. The result of MAKESASDATA can be used several times in the next layer or even for test purposes.

(5) In the layer PROCESSDATA (1..n) the analysis is done using the standard data set from the process MAKESASDATA. In this layer several analysis procedures are implemented. They are used to produce special computations and table outputs. With the same subset of data from the layers 0–4 different computations without a new data collection can be processed. As a result the data sheet, graphical output, and the process messages are passed to the layers' 6–7. Thus it is easy to pass a subset of data through layer 5 to 7 to get yet another specialized computation and output representation.

To satisfy all the different analysis needs it is advantageous to split this layer into several procedures. This facilitates the testing and adding of new functionality's.

DISCUSSION

The design of the second Swiss NFI will be characterized by the application of double sampling for stratification and ground observations on both permanent and temporary plots. The estimation of current values will be based on new and remeasured plots, the estimation of change will be based on remeasured plots only. Therefore the efficiency of SPR will not be fully used. On the other hand, dispensing with updated plots allows a simplification of the analysis procedures.

The proposed design is flexible for inventories on successive occasions, the estimation procedures are robust, and the combination with other data sets such as forest health monitoring, soil and vegetation surveys, and assessment of non-wood function is straightforward.

A transparent link between the estimation procedures and the data-analysis is guaranteed by the application of a data system and standard statistical software.

The main advantage of the presented data analysis is its independence from the actual state of the inventory data set. The flexible data passing mechanism of all layers allows only well defined relation. The data stream goes from one layer to the other. Specific computed variables for example single tree volume or site index are stored as attributes in the data base and only accessible for data analysis if these parameters are sufficiently tested. A transparent key definition with a sample plot identification and an inventory number easily allows for analysis of changes in subsequent forest inventories.

REFERENCES

Brassel, P., 1988. The Swiss National Forest Inventory – A Forest Information System, in: Kempf, A., Louis, R. (ed.): Information Systems for Forest-Related Subjects: Access, Search Techniques, and User Needs, Proc. of the Meeting of IUFRO S6.03, Zurich, 21.24 June 1988: 113–121

Cochran, W.G., 1977: Sampling Techniques, John Wiley & Sons, New York

Codd, E.F., 1990: The Relational Model for Database Management, Version 2, Addison-Wesley Publishing Company

EAFV, 1988. Schweizerisches Landesforstinventar: Ergebnisse der Erstaufnahme 1982–1986. Eidgen. Anst. Forstl. Versuchswes., Bericht No 304

Gertner G.Z., Köhl M.,1992: An Assesment of some Non sampling Errors in a National survey using an Error Budget, Forest Science (in press)

Hoare, C.A.R., Perrott, R.H., 1972: Operating Systems Techniques, Academic Press London and New York

Köhl, M., 1992: Statistisches Design für das zweite Schweizer Landesforstinventar: ein Folgeinventurkonzept unter Verwendung von Luftbildern und terrestrischen Aufnahmen (soon to be published)

Scott, C.T., 1990: TALLY: General data software for portable data recorders, Proc. Forest Growth Data: Capture, Retrieval and Dissemination Adlard, P.; Randeux, J., eds. April 3–5, 1989 Gembloux, Belgium. IUFRO. p.133–138

Tannenbaum, A.S., 1987: Operating Systems: Design and Implementation, Prentice-Hall

Zehnder, C.A., 1989: Informationssysteme und Datenbanken, B.G. Teubener Verlag Stuttgart 5. Auflage

FOREST RESOURCES INVENTORY AND INFORMATION SYSTEMS IN JAPAN

Kyoei Nishikawa
Resources Planning Section
Forestry and Forest Products Research Institute
Tsukuba, Japan

ABSTRACT

This paper describes a short history of forest inventories in private and national forests. Although recently hardwood volume survey has been carried out and acid rain and forest health monitoring is being implemented, for these two decades a forest register system has been the fundamental tool for forest management in Japan. The forest register system is now being upgraded to a forest information system or GIS. A forest register system combined with monitoring survey is recommended.

Keywords: Forest Register, forest Inventory, GIS

INTRODUCTION

In 1932 The Forestry Agency began to establish permanent plots for checking growth for yield table adjustments. Approximately 250 plots had been measured continuously up to 1992 in order to investigate growth and mortality response to silvicultural treatments.

The Forestry Agency (Kataoka 1984) conducted a large scale forest inventory in 1952 and regression analysis is applied to compare actual sampling data with the data in forest register. The accuracy of sampling error was 20 %. In 1953 The Forestry Agency carried out a national forest inventory, in which 3000 rectangular sampling plots (30Å–50m) were established on points of intersection of longitude and latitude under the assumption that accuracy of sampling error was 5% and coefficient of variation was 130 %.

In 1957 The Forestry Agency made an inventory manual based on stratified systematic sampling for private forests. In 1958 The Forestry Agency introduced a terrestrial sampling method combined with aerial photographs in national forest. One permanent plot per 500 ha (per 1000 ha in Hokkaido) was established and aerial photograph volume tables were constructed using these ground data.

In the 1980's stand density diagrams by locality and tree species were prepared throughout the country and based on these diagrams yield tables have been constructed according to silvicultural treatments.

FOREST REGISTER SYSTEM AND FOREST INVENTORY IN JAPAN

Forest Register System in Japan

Forest register system (Forestry Agency 1986) is fundamental to all types of forest management in Japan. It is a relational database which includes various types of forest information according to forest ownership and subcompartment. Items in the forest register are forest owner names, forest locations, area, tree species and mixture rate, stand age, volume, increment, site index, altitude, inclination, soil type, crown density ratio, assessment class of forest functions such as soil and water conservation, landslide and flood prevention and recreation etc.

Each prefectural government supervising private forests and each regional forest agency supervising national forests has its own forest register for local forest planning. The Forestry Agency aggregates these forest register data to calculate the national forest statistics, which is the main reason why integrated national forest inventory is unlikely to be incorporated in Japan.

The forested area of each private forest owner tends to be small and segmented with an average area of 0.5–1.0 ha. Prefectural and regional agencies prepare local yield tables by site and locality to input their volume information into the forest register. The forest owner's stand ages are checked and volume are updated automatically through the yield table computerized corresponding to the site.

Potential site indexes are estimated from outside qualitative data using the theory of quantification type I. Geographical information in the forest register is transferred from soil and geological maps. Potential assessment class of various forest functions are also estimated from outside qualitative data using the theory of quantification type II.

Site Index Estimation by Qualitative Environmental Data

Each prefecture makes site index curves of the main tree species through the stem analysis. The theory of quantification type áT makes it possible to estimate the potential site index by qualitative environmental data such as soil type, vegetation type, altitude, azimuth etc. (Forestry Agency 1986). These variables (items) are categorized and given a score for each category. Potential site index is obtained from summing up scores of the items at a certain point. Site indexes obtained are stored in the forest register.

Assessment of Forest Functions

The nation wide system (Forestry Agency 1986) started from 1977 to evaluate the potential of various forest functions such as wood production, water conservation,landslide prevention and recreation at grid level. These potential forest functions were assessed in three categories (high, medium, low) from outside qualitative or categorized valuables such as soil,slope,amount of rainfall,altitude using the theory of quantification type II.

The potential classes are put into items of the forest register and each prefecture makes an integrated forest function map based on the assessment classes for his forest planning use.

In 1990 the Forestry Agency classified the functions of national forests into four types of forests, that is, forests for land conservation, forests for preserving nature, forests for landscape and recreation, forests for wood productions using the assessment classes stored in the forest register.

PRESENT FOREST INVENTORY IN JAPAN

Felling Survey

The Forestry Agency (Forestry Agency 1986) undertakes a continual random survey in their area to ascertain details of felling and with this information ascertain the basic parameters of the Gentan Probability Distribution Model (Forestry Agency 1986) which was developed by Professor Suzuki and is used to forecast the output of private forests.

Felling survey is carried out to investigate silvicultural and felling trends. Approximately 126,000 sampling points of about 2.5 ha hectares each are set up on a nationwide level. Numbers of plots (n) are estimated from the following equation.

$$n = \left(\frac{tCv}{E}\right)^2$$

n = numbers of plots
t = coefficient of confidence
Cv = coefficient of variation
E = accuracy

Sample plots are systematically distributed for the ground survey. Items covered by the survey are felling method (final cutting or thinning and clear cutting or selective cutting), method of forest treatment(natural or man-made), tree species, stand age, felling rate, felling month, site index, felling volume.

These items are investigated using stump survey, forest register data, and yield tables. Felling area, volume and accuracy of sampling error are calculated from these basic data.

Natural Hardwood Inventory

From 1981–1986 the natural hardwood inventory started on a nationwide basis. Six stratums of the population of forest register data were made based on combinations of forest types (hardwood and mixed forests) and 5 stand age classes. Numbers of plots are calculated under the assumption that confidence limit is 95% and the standard deviation error is 15%.

Numbers of sample plots of stratums and intervals of sample plots are determined. Each sample unit comprises three concentric circular plots and on the smaller circular plot (0.02ha), all trees with a DBH over 4cm , on the medium circular plots (0.04ha) all trees with a DBH over 18cm and on the larger circular plots (0.1ha) all trees with a DBH over 36 cm are registered. Tree species are categorized and coded for computer procession. All tree heights are measured or tree height curves are used. Database and mapping system (Matsumoto 1992) were developed using personal computer (Apple Macintosh áUfx and NEC PC–9801 RA). The mapping system shows resource distribution maps and dominant hardwood species maps with polygonal unit of city level.

Acid Rain and Forest Health Monitoring System

A new continuous forest inventory system (Forestry Agency 1990) began in 1990 for monitoring at 5 year intervals damages to forests due to acid rain and other environmental impacts. The system consists of two parts: one is the nationwide forest inventory which the Forestry Agency conducts in cooperation with local prefectures and the other is a detailed survey of 8 observation areas.

To gather information about forest and environmental changes 1200 permanent sample plots are being established, each of which is chosen within grids of 20 km by 20 km. About 250 sample plots are scheduled to be set up for each year. Sample plots are chosen from the forest stands that have an area of over 1 ha and an age over 20 year and alsopossess a silvicultural forest record. One representative tree species within the grids is selected from Sugi (*Cryptmeria japonica*), Hinoki (*chamaecyparis optosa*), Akamatu (*Pinus densiflora*), Karamatu (*Lalix letolepis*) and natural stands etc.

Three concentric circular plots (0.02 ,0.04, 0,1 ha) were chosen for a complete tree tally (diameter and height),growth and mortality analysis. On the smaller plots all trees with a height over 1.3 m, on the medium plots all trees with a DBH over 4cm and on the larger plots all trees with a DBH over 18 cm are registered. Measurements of items are DBH, tree height, azimuth, slope, geology, site index, silvicultural register etc. Other items to be observed are forest decline above and underground, defoliation and soil. Disks or increment cores ere collected for annual ring analysis and fallen leaves, rainwater and soil are also collected for chemical analysis to clarify growth responses and environmental pollution.

Database system by GIS (ARISPLAN system on FACOM) was developed for data retrieval and mapping.

PRESENT FOREST DATABASE AND INFORMATION SYSTEM IN JAPAN

Forest register data are usually stored on magnetic tapes and used for many kinds of forest planning. Several prefectures have already introduced GIS (workstation and personal computer) combined with their forest register system. The results from questionnaire indicate about 40 % of prefecture and regional agencies intend to have GIS for their forest planning in the near future (Forestry Agency 1992)

In GIS they utilize forest register data for attribute data and subcompartment boundaries for mapping. But as various kinds of environmental data have been used in forest planning, some prefectures utilize the polygon and grid information such as National Numerical Data consisting of administrative district, altitude etc. developed by the National Land Agency and vegetation maps supplied by the Environment Agency.

On the other hand, the National Forest is developing an integrated forest information system based on forest register and silvicultural history records. The new system with distribution processing has the function of presenting up-to-date data, retrieval, processing and reporting. Each regional forest agency plans to adopt the new system from 1993.

DISCUSSION AND CONCLUSIONS

Traditional forest register systems are being changed into an advanced relational database and GIS systems. Japan has not conducted a national forest inventory from 1960 except for a nation wide hardwood inventory and acid rain monitoring system. The forest register system has both advantages and disadvantages. It supplies relatively accurate in-place information (which cannot be easily obtained by a sampling method) in spite of statistical ambiguity and is useful for comparatively large area planning.

It has also the disadvantage that the system has no function of monitoring what is actually happening in the forests. The continuous forest inventory system is good for monitoring changes of forest activities and environments.

Figure 1 shows a concept of new forest register system combined with national monitoring survey. It is recommended that the new monitoring system should be based on both remote sensing and an improved traditional felling survey.

REFERENCES

Forest Agency, 1986: Manual for Forest Planning ,Nihon Ringyo Chousakai, Tokyo, 1185p.*

Forest Agency, 1990: Manual for Acid Rain and Forest Health Monitoring System,33p.*

Forest Agency, 1992: Development of New Forest Inventory for the 21st Century, 156p.*

Hideo Kataoka,1984: Practices for Modern Forest Inventory, Nihon Ringyo Chousakai, Tokyo. 289p.*

Mitsuo Matsumoto, 1992: Geographical Estimation of Broad-leaved Forest Resources in Japan, Proc. of the Symposium on Integrated Forest Management Information Systems, 330–339.

(* in Japanese)

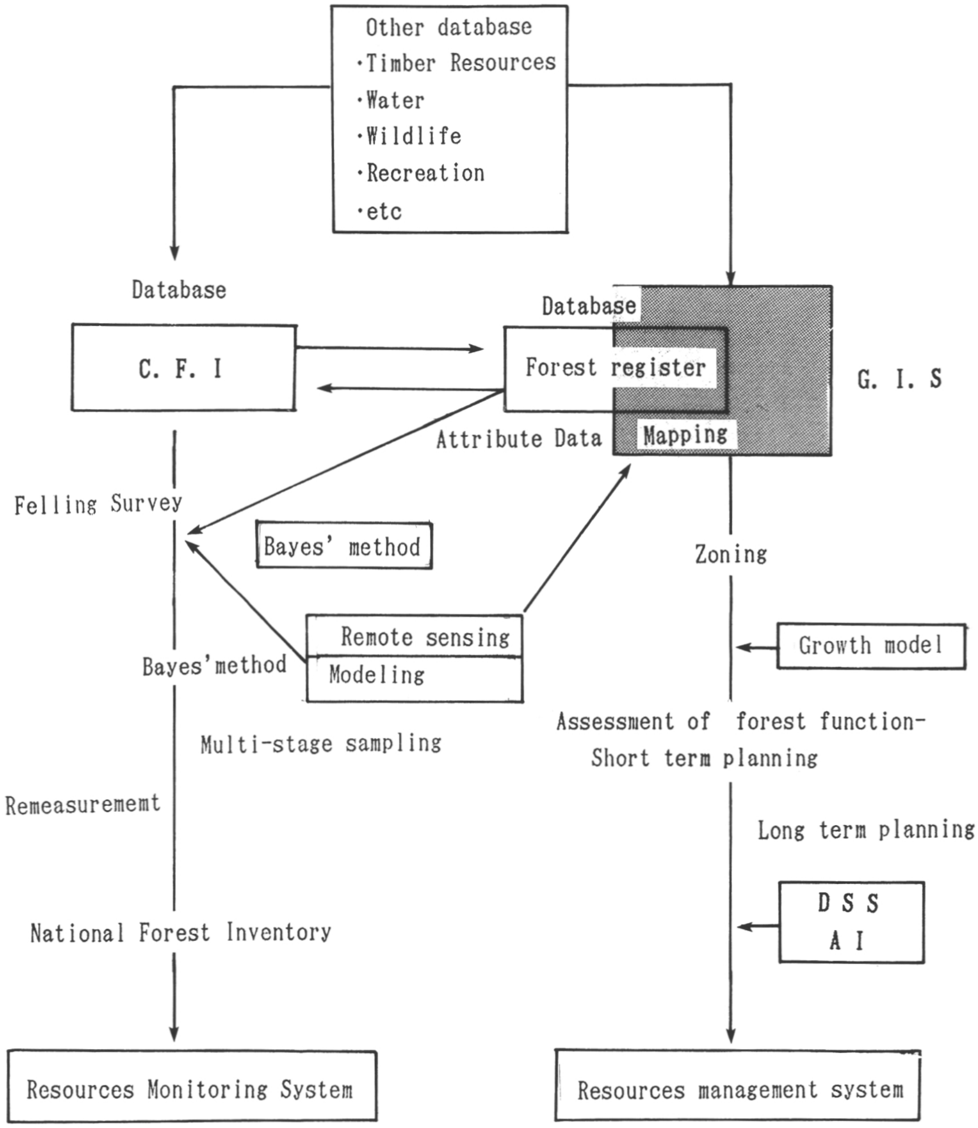


Fig 1 Combined C.F.I and Forest Register System

FOREST INVENTORIES IN BRAZILIAN AMAZONIA
A Desirable Reassessment

B. Rollet
F.A.O. Consultant
Rome, Italy

ABSTRACT

Two large regional forest inventories were conducted in Brazilian Amazonia. The FAO inventories (1956–1965) covered about 210.000 km2 south of the Amazon and east of Madeira river. The more ambitious RADAM BRASIL PROJECT (1968–1977) surveyed the whole Brazilian Amazonia i.e. more than 3 Million km^2.

In both cases some stratified random sampling was used with low intensities, ca 10^{-4} and 10^{-5} respectively. Methods and findings are compared and assessed.

Besides, a number of subregional forest inventories were carried out using various methods which are somewhat difficult to tie together for comparing results. Local small detailed floristic inventories are also available.

In spite of destructions and time elapsed large portions of information are still valid and await further processing and interpretation useful to forest policy, conservation and research.

Keywords: Amazonia, Brazil, inventories, procedures, reevaluation.

INTRODUCTION

The lowland complex called Amazonia is diversely defined and delimited. It is shared between 9 countries and covers ca. 7 Million km^2 half of which belongs to Brazil. After World War II, Amazonia became a political issue with many development programmes.

Only forest inventories will be discussed here. In order to facilitate their descriptions they are arbitrarily subdivided into three categories: regional, subregional and local.

Two large regional inventories were conducted in Amazonian Brazil with distinct ambitions and designs: the FAO inventories (1956–1965) and the Radam Brasil inventories (1968–1977).

While Radam Brasil was still at work, various Brazilian organizations became interested in more detailed subregional inventories.

Since 1953 many researchers working separately and in a rather erratic way carried out very detailed floristic inventories on small areas, a few hectares to one hectare or less.

THE FAO FOREST INVENTORIES 1956–1965

The objective was the identification of commercial volumes in the Amazon Basin. The inventories were conducted by D. HEINSDIJK, a Dutch forester who had previously gained experience in Surinam. FAO Report n° 2080: *Forest Inventories in the Amazon* (1965) summarizes the procedure and findings.

At that time adequate maps and aerial photos were very scarce. In order to obtain some representativeness HEINSDIJK and collaborators conceived a system of spatial stratification based on topography. Forest typification was done a posteriori according to the abundance of the main tree species and their frequency in the plots (% of occurrences).

Only trees 25 cm DBH and over were recorded on one hectare-plots (10 x 1000 m) in 10 cm diameter categories. A fair amount of dendrometric measurements was analyzed in volume tables, but without growth studies.

An effort was paid for the correct scientific naming of tree species. Even so, many species belonging to difficult groups (*Eschweilera, Lecythis,* Sapotaceae, Burseraceae...) were pooled under broad vernacular names and possibly with inconsistencies between teams and from one region to another (a well known difficulty in tropical forest inventories), therefore resulting in a drastic subestimation of the tree species richness : about 400 spp. on 1381 ha scattered among 20 Million hectares.

This is one of the major weaknesses in HEINSDIJK's inventories; on the other hand these inventories were essentially based on field work, i.e. without aerial photography support.

However that was a pioneer work in tropical foresty and one of the very first quantitative evaluations, more or less contemporary with the Zaire surveys (compiled by PIERLOT, 1966) and with the Malaya inventories (summarized by WYATT-SMITH, 1963).

RADAM BRASIL PROJETO (1968–1977)

FAO inventories had paved the way and brought external aid and expertise.Radam Brazil Project was conceived and carried out entirely with internal means.

The objective was a general survey of natural resources to supply a basis for the development of the Amazon region in five main aspects: geology, geomorphology, soils, vegetation and land use, and their respective mapping.

Instead of conventional air photography, all weather radar techniques were used to obviate often cloudy conditions. New data collecting techniques were devised. Data processing and patterns of publications were kept uniform throughout the project with few exceptions. Only the aspect vegetation and forests will be considered here.

Brazilian Amazonia is subdivided according to a rectangular pattern 6 degrees of longitude, 4 of latitude (see map).

Forest typification is purely morphological and derived from Radar imagery. The very detailed stratification is later on simplified into major forest formations for practical reasons of sampling which is roughly proportional to strata areas. An example is given for Rio Purus sheet.

RIO PURUS Sheet R. 293.760 km2 (see map)

Number of one hectare-plots	Area (km2) of stratum	Forest (or vegetation) types according to	Strata Relief
103	142.888	Closed rain forest	Low plateaux
29	11.972	Closed rain forest	Dissected relief
23	25.410	Closed rain forest	Alluvial
20	10.981	Closed rain forest	Plateaux
7	1.132	Closed rain forest	Lower montane
15	36.379	Open rain forest	Low plateaux
8	18.697	Open rain forest	Alluvial
6	2.002	Open rain forest	Dissected
33	16.746	Open rain forest	Secondary forest
subtotal 244	266.157	All forests	Sampling intensity ca 10^{-5}
Not sampled	27.603	Savannas (1.925) ; Contact savanna forest (15.246) ;Agriculture (17) ; Depression (3.824) ; Inundated area (2.378)	
TOTAL	293.760	All vegetations types	

A main feature of the project is the importance of air logistics. Field sampling was carried out by helicopter borne-teams: each team had to enumerate one hectare and identify tree species over 100 cm GBH (girth breast height) per working day.

For conversion into volumes HEINSDIJK findings were used and form factor 0.700 was adopted. An improvement in scientific identification is noteworthy (except for the first sheets, such as Belém and Araguaia sheets) e.g. 402 species (353 fully determined) for Manaus sheet (296.160 km2), on 214 sampled hectares; 457 (434 fully determined) for Rio Purus; possibly ca. 800 tree species for the whole Brazilian Amazonia whereas the FAO inventories had recorded only about 400 tree species on 1380 ha.

Owing to Radam Brazil inventories large tree populations can be evaluated for any particular tree species. (The most abundant species in 623.000 km² (Boa Vista, Manaus and Rio Purus) is *Eschweilera odora* (Poepp.) Miers with about 199 Million trees 32 cm DBH and over. The second most abundant is *Goupia glabra* with ca. 94 Million trees. Radam inventories list also the rarest species.

SUBREGIONAL FOREST INVENTORIES

The Table *infine* shows the main characteristics of 22 subregional inventories (n° 3 ton° 24): areas between 200 and 91.000 km², at least 8 different sampling designs (random stratified-, cluster-, systematic),...); sampling units 0.1 to 1.0 ha of various shapes; intensities in per thousand: 0.005 to 10; lower DBH 20 to 45 cm, in some cases 10 cm. The number of recorded tree species, as a function of the enumerated area is highly indicative of the inventory quality.

The most accurate in this respect is probably inventory n° 20 along the Manaus-Itacoatiara road which was supervised floristically by W. RODRIGUES of INPA Manaus; 421 tree species 25 cm DBH and over were identified on 27 ha. The second best could be inventory n° 22 (Jari) but results were restricted and could not be fully analyzed.

In the opinion of the botanists even the best subregional forest inventories subestimate the floristic richness whose reality is understood only through very detailed enumerations of small plots.

SMALL LOCAL DETAILED INVENTORIES

A Few Examples

See map for location of inventories n° 25 to 31 and bibliography.

Transects 5 m wide with all species 1 m total height and over are among the most accurate available inventories. The number of tree species above 10 cm DBH occurring on one hectare is a convenient basis for comparison, e.g. 108 species 10 cm DBH and over on one ha (inventory n° 25); 179 species 15 cm DBH and over (with 56 species 5 to 15 cm) on one ha (inventory n°29).

Some areas have been investigated in great detail e.g. near Belém (on Embrapa estate) or near Manaus (Ducke reserve) on a few hectares with various objectives (forest vertical structure through transects, spatial distribution of individual species, floristic richness).

These tiny areas lying far apart, lost in the Amazonian immensity without concerted design just yield pinpoint information on floristic diversity and illustrate the gaps of ignorance and the inadequacies of the approximate knowledge given by the large conventional inventories.

POPULATION ASSESSMENT OF VALUABLE COMMERCIAL SPECIES

Commercial species are usually rather well identified in the field. Large inventories give a fair idea of their populations and growing stocks through stand tables. Assuming careful growth rates, reasonable annual cuts can be derived along with conservation measures. As examples the populations of 4 commercial species in 3 regions have been estimated from Radam Brasil Report in million trees 32 cm DBH and over.

			Boa Vista	Manaus	Purus	TOTAL
		Forest area km^2	94.763	262.219	266.157	623.139
		Total area km^2	250.740	295.160	293.760	839.660
Scientific name	Commercial name	Vernacular name				
Goupia *glabra*	Goupi	Cupiuba	5.25	63.51	24.85	93.62
Virola *surinamensis*	Baboen	Ucuuba da varzea	2.59	16.54	14.09	33.22
Carapa *guianensis*	Crabwood	Andiroba	0	1.78	5.20	6.98
Cedrela *odorata*	Red Cedar	Cedro vermelho	0.47	0.31	0.79	1.57

One can expect on a square kilometer of forest an average of 0,25 Cedrela (tree 32 cm and over), 1.0 *Carapa* , 5 *Virola*, 15 *Goupia* with a broad variation between the regions. A figure such as 1.57 million trees of *Cedrela* 32 cm DBH and over means roughly 800.000 trees 30 to 40 cm, 400.000 trees 40 to 50, 200.000 trees 50 to 60 and 100.000 exploitable (60 cm DBH and over), not necessarily sound and with very erratic spatial distribution i.e. an annual potential cut between 3.000 and 5.000 trees, based on a conservative working plan of 30 or 20 years on 623.000 km^2. This example illustrates the danger of creaming or careless over exploitation of rare species. Similar statistics could be given for roughly 560 species occurring in the three regions considered as a whole.

CONCLUSION

Projeto Radam Brasil (1968–1977) has been one of the major world inventories in tropical rain forest allowing fairly unbiased extrapolations on tree species populations.

Though limited to trees 32 cm DBH and over, the compiled stand tables i.e. distribution by species and diameter classes of tree numbers (or volumes) give insights on the balanced/ unbalanced situation of species, especially when compared with inventories down to 10 cm DBH available in nearby countries.

Unfortunately growth studies have been greatly neglected in past inventory operations. Assuming reasonable growth rates the stand tables suggest minimal management rules for allowable cut and conservation of rare and endemic species.

Only large inventories can give a sufficient wide vision on forestry problems and a sound basis for developing a rationale for regional policies.

Being now 20 to nearly 40 years old and in spite of subsequent destruction estimated at ca. 10 % (farming, logging, roads,...), the Amazonian regional inventories still retain much information.

This is of course true for more recent subregional inventories.

RECOMMENDATIONS

– Field data should be properly stored and eventually reworked. Additional data processing can yield valuable information which is not shown in FAO or RADAM BRASIL reports: versatile grouping of results, assessment of species populations, especially the minute populations of rare species, spatial distributions of species, identification of tree communities, reassessment of vegetation mapping in the Amazon Basin.

– Large regional forest inventories are costly. Each one reflects the capability of harnessing all the technologies available at a time and marks a stage in knowledge. It would be unwise to recommend a third Amazonian forest survey unless substantial improvements in methodology be decided.

– Suggested additional items for future inventories may be: optimized designs, standardization of measurements, subsampling in the undergrowth and canopies, regeneration-growth-biomass-communities studies, floristic richness modelization, search for refuges, conservation of rare species, enforcement and study of protected areas.

REFERENCES

– Regional inventories:

Heinsdijk et al. ,1958–1965. FAO Reports 601/949/992/1250/1284/2080

Glerum et al., 1960–1962. FAO reports 1271/1483/1492/1562

Projeto Radam Brasil, 1968–1977. Reports on sheets A to T corresponding to volumes 1 to 19 (except sheet K) and the northern half of Brazil.

– Subregional inventories:

Bastos, A. Miranda, 1960. A floresta de Amapari-Matapi-Cupixi. Bol. n° 2. Setor Inventarios florestais. Min. Agric. Rio de Janeiro, 54 p.

IBDF-GAO, 1972–1975. Inventario florestal Santarem-Cuiaba, Rodovia Transamazônica.

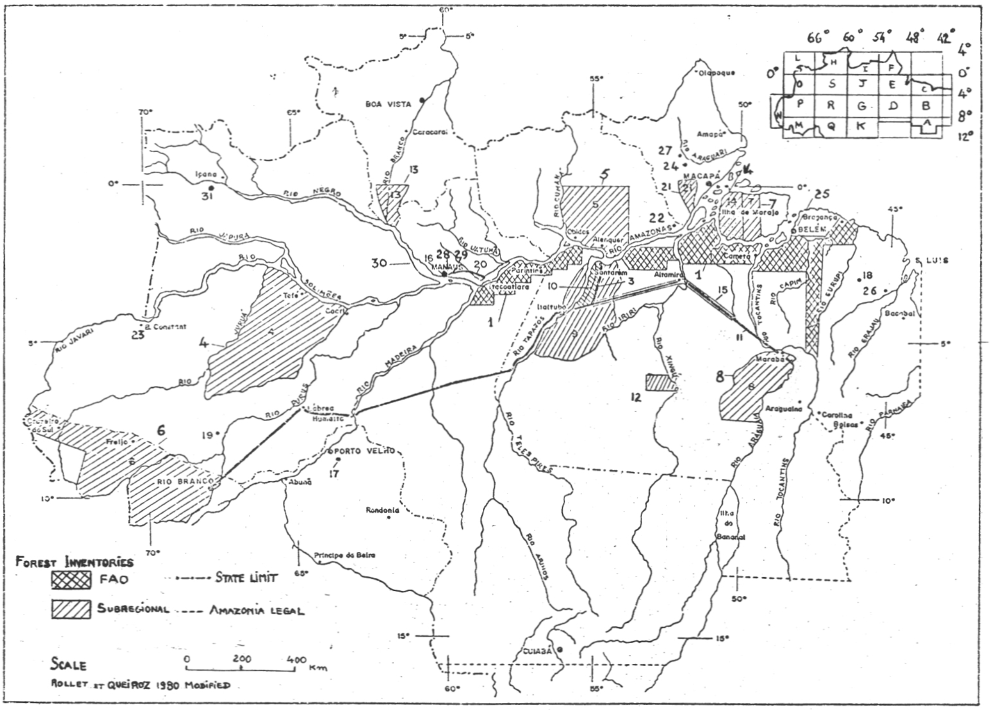
IBDF-POLAMAZONIA, 1976–1977. Inventorio florestal de reconhecimento (Acre, Marajo, Tapajos, Jurua-Solimões, Trombetas).

IDEP, 1975. Inventario florestal. Estuario du Rio Amazonas. Marajo.

Rodrigues, W.A., 1967. Inventario florestal pilôto ao longo da estrada Manaus- Itacoatiara. *Atos simposio Biota Amazônica* Vol. 7 : 257–267.

Rollet, B., Queiroz, W.T., 1980. Observações e contribuições aos inventarios florestais na Amazônia. 31 Congr. nac. Botânica. Itabuna, 10 p., Mapa.
Sudam, 1974–1977. Inventario florestal : São Felix do Xingu 143 p., Rio Branco, 199 p.

– Small detailed forest inventories. Examples. See site number on map
25 Cain, S.A. et al., 1956. *Amer. J. Bot.* 43 (10): 911–941
Pires, J.M. et al., 1953. *Botanical Gazette* 114 (4) : 467–477
26 Flor, H. de Miranda, 1967. *Atos Simposio Biota Amazônica* vol. 7 : 147–163
27 Rodrigues, W.A., 1963. *Bol. Museu Goeldi,* Nov. ser. Botânica n° 19, 22 p.
28 Rodrigues, W.A., 1971. *Acta Amazônica* 1 (2) : 17–18
29 Prance, G.T. et al., 1976. *Acta Amazônica* 6 (1) : 9–35
30 Rodrigues, W.A., 1961 : 209–265 in Aubréville : *Etude écologique des principales formations du Brésil,* 268 p.
31 TakeuchiI, M., 1960. *Bol. Museu Goeldi* Botânica 6–7–8 : 17 + 14 + 13 p. Also in English, 1961–1962. *J. Fac. Sci. Univ. Tokyo* sect. 3 (8) : 1–26 ; 279–288 ; 289–296.



NATIONAL INVENTORIES SERVING GLOBAL MONITORING OF FOREST RESOURCES
The Chanaian Experience

Michael Yaw Poku-Marboah
National Service Personnel (B.Sc. Nat. Res. Mgt) [For]
Forest Resources Management Project,
Forestry Department, Ghana

ABSTRACT

Man's interaction with the forest dates as far back as ancient times, yet the concept of conservation and management of forests for its wise-use is a recent development. However, to manage a nation's forest resources properly information relating to what is growing, condition of growing resources, where it is growing, what quantities and at what rate it is growing become indispensable.

Three national forest inventories have been undertaken in Ghana since the 1950s. The most recent one which saw the re-vitalisation of the Permanent Sample Plot programme, took place between October 1985 and November 1988 and covered an area of 546,000 ha consisting of 43 forest reserves.

The results of the inventory led to:

a. reclassification of tree species in the forest,
b. determination of national volume estimates – 188 million m3,
c. increment determination from Permanent Sample Plots (P.S.P.s) – 5mm/yr (average),
d. determination of time of passage and tree age for various species,
e. determination of growth of stands,
f. formulation of individual species yield table and annual allowable cut,
g. determination of forest growth estimates from Ghana Forest Simulation Model GHAFOSIM", and
h. determination of depletion rates of the forest resources

Together with these basic management information, the national forest resources are being monitored through the P.S.P. system.

Though forest resources cover wildlife population, sources of freshwaters and their fishes, it must be emphasized that, in Ghana, not much has been done with regards to their inventory.

Keywords: Inventories, monitoring, forest resources, Ghanaian

INTRODUCTION

Man's interaction with the forest dates as far back as when the first homo-sapiens appeared on the earth. As long as his food and shelter needs were readily met by the forest, man saw no reason to manage this resource since in his estimation the forest was unlimited in the supply of its resources. However, with increasing human populations with its attendant needs more pressure was brought to bear on this "seemingly inexhaustible" resource. Among the factors that influenced the idea of conservation were;

(i) shortage of forest products such as fuelwood and timber in Europe in the middle ages,

(ii) effects of deforestation due to uncontrolled clearing of forests for farming and timber exploitation in countrieswhich were previously covered with rich natural forests.

Although the realisation of the need for conservation of forests goes as far back as 450 B.C., planned management of forests for the wise-use of timber and (non-timber forest products) as well as for environmental protection is a recent development.

FORESTRY IN GHANA

In Ghana land-use practices have always been in conflict with forestreservation with slash and burn agriculture being the most offensive culprit. It was not until 1909 upon the recommendation of H.N. Thompson, a Conservator of Forests from Nigeria, that a Forestry Department was set up with the original task of conserving and protecting forests which had been declared public property for economic or strategic reasons. The Forest Ordinance backing this task was enacted in 1927 by the then Colonial Government.

Forest Management in Ghana

The main aim of forest management is the provision of the greatest benefit to the greatest number of people for all time. Herein lies the doctrine of sustained yield (Baidoe 1968).

However, to manage a resource sustainably, a lot of data are required. These include, what is growing, in which area it is growing, condition of growing stock, what quantity and the growth rate of the resource. Data need to be collected to forecast what changes in state of organisation may be expected if certain treatments are imposed.

In Ghana, forest management began after World War II. Prior to this time management was restricted to protection and boundary maintenance with inventory and silvicultural research on a small scale.

NATIONAL FOREST INVENTORIES

Three national forest inventories have been undertaken in Ghana since the 1950s. The first of its kind was carried out between 1952 and 1970 with a sampling intensity of 3–5% and a sample size of 2 plots per 2.59sq.km of productive high forest. Since this was the first time and the dynamics of the forest was not well known, some assumptions had to be made which included; the time of passage from one girth class to another, time taken by a tree to reach maturity, and the mortality losses in the various girth classes.

In order to obtain more information on the dynamics of the forests for future management, Permanent Sample Plots (P.S.P.s) were started in 1969. The Leading Desirable (LD) concept was used to determine which trees to record in the sample plot. A LD was any economic tree or seedling which was likely to be of most value at the next felling cycle.

The second national inventory which was under the sponsorship of the Food and Agriculture Organisation and the United Nations Development Programme (FAO/UNDP) had a sample size of just over 150 000ha with a sampling intensity of 5% This was between 1980 and 1983.

Towards the end of the most recent one (1985–1988), the Forest Inventory Project (FIP) which was at a sampling intensity of 0.25% and covered an area of 546,000ha consisting of 43 Forest Reserves, the P.S.P. programme was re-vitalised.

This time, the LD concept was considered inappropriate for long-term studies of forest change. The main reasons assigned were that, firstly, tree recruitment, mortality and competition can only be fully understood when the entire tree population is monitored, secondly, economic value of tree species is liable to change over time. In addition, the very low recovery of LD's meant that the information to be obtained was limited. It was therefore decided to measure all trees greater than 10cm diameter at breast height (dbh).

The Forestry Department's P.S.P. programme has one main and several subsidiary objectives, namely:

to provide the data required for modelling natural forests

and hence:

- predict future yield of specific products; estimate the effect of site, and disturbance, on forest composition and production; and monitor long-term site changes.

Plots have been laid out in proportion to the area of Forest Reserves within each of the major forest types described by Hall and Swaine, 1981, with few modifications to suit local conditions. Within each Forest Management Unit (50,000ha), 10 plots have been randomnly located within a variable number of strata. Strata identified to-date are:

topographical position;	hill top, upper slope, lower slope, valley bottom, swamp
logging history;	recent logging, no logging

Six hundred plots (350 new and 250 old) believed to be manageable in the long term and sufficient to provide the information required have been established. The most significant recent addition to the field procedure is the measurement of a sub-sample within the plot for saplings (trees with dbh in the range of 2–10cm). This was to introduce regeneration surveys in P.S.P.s. Times between successive measurements have been set for 5 years.

The F.I.P. itself had among others, two main objectives;

(i) static inventory
Under the static inventory estimates of the national stock of commercial log volume within the Forest Reserves of Ghana were found. This was done by means of Temporary Sample Plots (T.S.P.s). The need for this was critical as the rehabilitated timber industry was putting ever increasing pressure on the forest. The resultant concern was that demand was outstripping supply, and

(ii) dynamic inventory
Under this the objective was to update the Department's system of dynamic inventory by means of Permanent Sample Plots (P.S.P.s).

Results: National Forest Inventory

The results of the F.I.P. led to:

a. reclassification of tree species in the forest,
b. determination of national log volume estimates,
c. increment determination from P.S.P.s,
d. determination of time of passage and tree age for various species,
e. determination of growth of stands,
f. formulation of individual species yield table and annual allowable cut,
g. determination of forest growth estimates from "GHAFOSIM", and
h. determination of depletion rates of the forest resources.

Reclassification of Tree Species (F.I.P. classes)

The Project highlighted the fact that some of the "more desirable" species were being cut faster than they could regenerate whereas others were growing faster than they were being cut. For a trade-off between the industry's silvicultural role (logging) and the maintenance of the biodiversity of the forest environment,a wider species base of commercial trees had to be encouraged.

This has been partly achieved by re-classifying all tree species into 3 groups based on the natural size,frequency, and past and present export potential. The F.I.P. classes 1 and 2 have 66 and 60 species respectively whilst all the remaining tree species fall within FIP class 3.

Determination of National Log Volume Estimates

The presentation of the standing volume is based on the FIP species classification.

In Ghana, the reserved forest area is divided into three Working Circles (W.C.). These are Production Working Circle (73%) , over which logging is permitted and the forest is managed for the sustainable yield of timber; the Protection Working Circle (27%) over which no logging is permitted and the forest is managed solely for environmental protection; and the Research Working Circle (insignificant) in which the forest is managed for the purposes of scientific research. The entire high forest zone covers an area of 1.8 million ha.

The estimates of standing volume which consist of trees with marketable form and quality are the product of the mean volume of timber for each species on one square kilometre of forest land and the productive area of forest in square kilometres.

The gross national standing volume is estimated at 188 million m^3. This is made up of about 102 million m^3 of volume in trees greater than 70cm dbh (lowest cutting limit at time of writing) and about 86 million m^3 in trees less than 70cm diameter. The distribution between the FIP classes is presented below in Table 1.

The Production Working Circle area was used as the "bulking up" factor for the results.

Table 1. National Volume Estimates 1989

Diameter Range	FIP Class	Volume (m^3 x 1million)	Percentage
30–70cm	1	54.5	28.9
	2	23.4	12.4
	3	9.4	5.0
>70cm	1	89.7	47.5
	2	11.1	5.9
	3	0.5	0.3
Total		188.9	100.0

Increment Determination from P.S.P's

In all 256 P.S.P.'s were measured comprising about 11,000 tree increment measurements. This covered 14 tree species and the typical growth was around 5mm/yr. This varies from nil to 20mm/yr or more. Species show characteristic differences in growth rates. *Triplochiton scleroxylon* (Wawa), *Piptadeniastrum africanum* (Dahoma) are fast growing and have a growth rate of 8–10mm/yr and *Milicia excelsa* (Odum) grows 4–5mm/yr.

Determination of Time of Passage and Tree Age

By dividing increment into width of a diameter class, the average time it takes a tree to grow through that class can be estimated. For example to grow from 50cm to 70cm diameter Wawa takes 29 years. By adding together "the times of passage" up to the mature size the average time it takes to grow a mature tree can be estimated. Wawa requires 75 years to reach 70cm. (See Table 2).

Determination of Growth of Stands

Traditionally in natural forest management, the growth of the stand has been determined by measuring the increment of individual trees. But individual tree increments have been found to give little information about how stands of trees grow. Each tree is subject to competition from neighbours, and its growth rate varies enormously depending on that competition. Trees are also continually dying. Of those trees which reach 10cm diameter, only about 10–20% will survive to 100cm. This also depends very much on species and the characteristics of life span, growth rate, and shade tolerance.

These interactions between trees are also much affected by the treatment of the stand. Logging opens up the canopy and encourages rapid growth of small trees. At the same time, mortality is greatly accelerated as a result of sudden physiological changes and direct logging damage.

Because of the complex problems, estimates of stand growth and annual allowable cut (AAC) discussed below must be regarded as very provisional.

Formulation of Individual Species Yield Tables

Yield tables for 3 species selected out of 14 species sampled on the old P.S.P's are presented in Table 2. For each species, the stocking, from the T.S.P.s is shown by diameter classes. Also the median tree volume of each class is known. Average increments for each class summarized from P.S.P.s are given. Time of passage through each class is calculated as class width (200mm) divided by mean increment.

The growth shown refers to the volume that will grow into a class from the class below. It is calculated as the volume of the preceding class, times the average proportion of surviving trees, times the average percentage that will move up into the next class.

The AAC is the increment into a class times the total productive forest area, assumed in these table as 1.3 million ha. It assumes that the class lower boundary is taken as the felling diameter limit.

For example, for Odum, the 120cm class includes trees 110cm and above. The average growth into that class is $0.022 m^3/ha/yr$ nationally. This is the volume that could be felled on a sustained basis to that size limit.

Table 2. Yield Tables for 3 selected species, Odum, Wawa, Dahoma.

ODUM	Diameter	cm	10–29	30–49	50–69	70–89	90–109	110+
	Tree Vol.	m^3	0.38	1.60	3.69	6.69	10.61	15.47
	Stocking	N/ha	0.36	1.17	0.13	0.09	0.07	0.07
	Increment	mm/yr	3.31	3.75	4.86	5.93	5.93	5.86
	Timepass	yrs	60.48	53.39	41.14	31.14	33.70	34.13
	Growth	m^3/ha/yr		0.001	0.004	0.008	0.014	0.022
	AAC	m^3/yr		1395	5059	10503	18068	28650
WAWA	Diameter	cm	10–29	30–49	50–69	70–89	90–109	110+
	Tree Vol.	m^3	0.30	1.56	4.08	8.06	13.68	21.06
	Stocking	N/ha	2.03	1.01	0.90	0.76	0.48	0.36
	Increment	mm/yr	9.18	8.54	6.74	6.78	5.50	4.60
	Timepass	yrs	21.78	23.42	29.67	29.49	36.36	43.48
	Growth	m^3/ha/yr		0.014	0.060	0.104	0.131	0.135
	AAC	m^3/yr		18206	77944	135779	170558	
DAHOMA	Diameter	cm	10–29	30–49	50–69	70–89	90–109	110+
	Tree Vol	m^3	0.36	1.47	3.36	6.05	9.54	13.84
	Stocking	N/ha	2.75	0.61	0.44	0.31	0.18	0.12
	Increment	mm.yr	5.94	8.98	11.15	8.32	5.82	5.82
	Timepass	yrs	33.66	22.28	17.94	24.04	34.39	34.36
	Growth	m^3/ha/yr		0.006	0.029	0.058	0.045	0.033
	AAC	m^3/yr		8418	37751	75569	58904	43278

Determination of Growth Estimates From “GHAFOSIM”

Ghana Forest Simulation Model (GHAFOSIM) is a much more sophisticated approach to estimating forest growth. It is a simulation model which takes account of the probability distribution of increment, stand density and tree mortality rates.

The model in its current form only projects two species groups; commercial species, and non-commercial species. The former includes all species which have ever been exported.

The model suggests that for the commercial species as a whole, production rates of 1/m^3/ha/yr (equivalent to today’s rates of felling), can be sustained over 100 years or more, but that in the process, the forest becomes progressively depleted in stocks of commercial timber.

The model suggests that a cutting cycle which will maintain the present distribution of size classes will have to be about 100 years or so. Shorter cycles, whether 25, 40 or 60 years, deplete the existing stocks of mature trees and result in lower average yields or about 0.6m^3/ha/yr, in the second cycle.

Determination of Depletion Rates of The Forest Resources

Mature trees of about 1 metre diameter are normally at least 100 years old and often 200–300 years for the slower growing species, including many traditional decorative timbers. It is considered a controversy to realise how fast Ghana is felling, traditional species. Table 3 shows estimated resource life for the 14 species for which good increment data is available.

Table 3. Estimated resource life for some commercial species

Species	Girth limit	Resource > Glimit m^3	Annual growth m^3/yr	Rate of extraction m^3/yr	Resource life yrs
Odum	110cm	1 408 000	28 650	172 983	10
Edinam		468 000	7 155	33 167	18
Sapele		702 000	13 496	41 135	25
Utile		465 000	8 081	31 891	20
Mahogany		692 000	31 488	66 877	20
Afromosia		0	0	7 190	0
Wawa	70cm	26 356 000	135 779	366 064	114
Guarea		524 000	4 592	10 972	82
Dahoma		5 254 000	75 569	14 915	***
Kyenkyen		3 726 000	33 331	14 801	***
Hyedua		154 000	1 966	10 620	18
Mansonia		695 000	2 753	5 830	226
Danta		1 254 000	10 098	24 787	85
Avodire		2 365 000	13 548	269	***

*** Growth exceeds felling rate. There is a net increase in the resource. These species should be exploited more heavily.

Table 3 shows that the traditional redwoods and Odum are likely to be exhausted within 2–3 decades at present rates of felling. Wawa, the present most heavily felled species (32% of all forest extraction), has a stock life of about 114 years. Given the conservative nature of the yield tables, this approximates to a sustained yield and is acceptable. Species such as Dahoma, and others are underutilized.

This analysis could be extended to other important species like *Terminalia ivorensis, Terminalia superba* and Ceiba pentandra which are felled in large volumes and are also quite ubiquitous. Unfortunately, there is no accurate data on their growth rates. This emphasises the importance of an investment in more PSP's with a more appropriate sampling design.

CONCLUSION

With the results of the national forest inventory, Management Plans are being drawn. This document which constitute the guiding principles for the management of the reserves, aims at:

a. managing the forest for the optimum and continous production of wood for timber and non-timber products,
b. increasing by silvicultural treatment or management practice the proportion of tree species of known and potential commercial value in the forest stands and if possible to accelerate their rates of growth,
c. maintaining the protective role of the forest, and
d. satisfying the reasonable demands of the local population for forest produce.

This document therefore, prescribes the yield to be removed per period of time, the felling cycle, logging procedures, reforestation programmes, silvicultural treatment of the forest, forest growth studies and many other prescriptions related to the management of the resource.

Together with these basic management information available, the national forest resources are being monitored through the P.S.P. system.

It must be emphasized, however , that inventory of non-timber forest products such as canes, rattans, chewsticks, sponges marantaceae leaves are currently being undertaken under the Participatory Forest Management of the Forest Resources Management Project.

With regards to wildlife populations, sources of freshwaters and their fishes, not much has been done by way of inventory in Ghana.

REFERENCES

Alder, D., 1989: Natural Forest increment, growth and yield. Ghana Forest Inventory Project Seminar Proceedings, Accra, 29–30 March, 1989. Pp. 47–49.

Baidoe, J.F., 1968: An approach to management using sample plots in Ghana. Special subject study at the Commonwealth Forestry Institute. (Unpublished)

Baidoe, J.F., 1970: Yield regulation in the High Forests of Ghana. In Development of Forestry in Ghana by Bennuah, S. 1987. Pp. 31–32.

Bennuah, S., 1987: Development of Forestry in Ghana. B Sc Natural Resources Management dissertation, Institute of Renewable Natural Resources, University of Science and Technology, Kumasi, Ghana. (Unpublished).

Bird, N.M. and Sackey, E.P., 1991: The Permanent Sample Plot Programme, Ghana Forestry Department. (Unpublished).

Blackett, H.L., 1989: Forest Inventory Methods. Ghana Forest Inventory Project Seminar Proceedings, Accra, 29–30 March, 1989. Pp. 14–22.

Francois, J., 1989: Introduction and History of the Project. Ghana Forest Inventory Project Seminar Proceedings, Accra, 29–30 March, 1989. Pp. 6–7.

Ghartey, K.K.F., 1989: Results of the Inventory. Ghana forest Inventory Project Seminar Proceedings, Accra, 29–30 March, 1989.

Owusu, J.G.K., 1989: Introduction to Seminar. Ghana Forest Inventory Project Seminar Proceedings, Accra, 29–30, March, 1989. Pp. 3.

FOREST INVENTORY IN THAILAND – PAST, PRESENT AND FUTURE PERSPECTIVES

Songkram Thammincha
Faculty of Forestry
Kasetsart University
Bangkok, Thailand

ABSTRACT

Forest inventory operations in Thailand are of two main types : national forest inventory and working plan inventory. The first national forest inventory was carried out during the years 1955 to 1960 with an assistance from FAO. Cluster sampling with camp unit system, 288 plots in 6 squared-tracts per camp, was employed and the data recorded from 0.1–ha circular plots.

Modified camp unit system was employed during the second and the third national forest inventories, i.e. 1969 to 1976 and 1977 to 1981 respectively. Under this design, one camp consisted of 320 plots from 4 units of 4 tracts each. Thirty four permanent camps or 10,880 plots were established for continuous monitoring of forest resources: 8 camps in the North, 9 in the Northeast, 9 in the Central, and 8 in the South. Unfortunately, only two measurements could be made since the majority of the plots were severely deforested.

During the second half of the 1980s, the pilot studies on selective sampling with lines of fixed area plots and polyareal plots (point sampling) were carried out in northern part of the country with the cooperation of ASEAN Institute of Forest Management (AIFM). The pilot studies on fixed-area plot, strip and point samplings was carried out in tropical rain forests of the South in 1990 and 1991 as part of the permanent monitoring of tropical rain forest in ASEAN countries.

The current national forest inventory tends to cover the period from 1992 to 1996 which corresponds to the time frame of the 7th National Economics and Social Development Plan. L-shaped clusters, 4 km apart from each other, with 9 plots in each cluster, will be employed covering an area of 14,341,700 hectares. The data and information from this inventory will serve national, regional and global monitoring of forest resources.

INTRODUCTION

Forest resource management in Thailand can be dated back as early as 1896 when the Royal Forest Department was founded. Since then a different kinds of inventories have been carried out but almost none has been recorded. A significant development of forest inventory occurred during the 1950s with an assistance from FAO. In 1953, a "profile sample plot method" was introduced by Mr. Gongrup, but this work was not recorded, and finally faded out.

The first national forest inventory was started soon after Prof. Dr. F. Loetsch introduced the inventory designed called "Camp Unit System" in 1955. This design was employed in forest inventory operations in different parts of the country up to 1960.

Since then, the system has been modified and employed in different levels of inventory operation in different periods of time, i.e. 1969 to 1976, 1977 to 1981, 1982 to 1986, and 1987 to 1991.

An other step of forest inventory development was marked in 1989 when L-shaped cluster was introduced and tested in different parts of the country. This design will be employed during the next national forest inventory, 1992–1996.

The historical background of forest inventory in Thailand sounds very impressive, but very little have the inventory results been used for forest resource management. With the logging ban since 1989 and the very delicate problems of forest land resource management, it is believed that more emphasis will be placed on regular monitoring of forest land use, and multiple resource inventory will replace the traditional timber surveys.

INVENTORY DESIGNS

Camp Unit System

The lay-out of Camp Unit System used during the first national forest inventory is shown in Annex 1. One camp consists of 288 plots on six square tracts of 480 x 480 m, 48 plots on each tract. The distance between plots is 40 meters, and the distance from unit center to each tract is 1,000 meters.

The sample plots are so-called concentric circular plot comprising of 3 plots of different sizes with the same plot center as follows.

Plot radius, m	Area, ha	Type of record
5.64	0.01	Seedling and sapling enumeration
12.62	0.05	Small tree (gbh < 30 cm) enumeration
17.84	0.10	Tree (gbh > 30 cm) measurement

Camp Unit System yields maximum sampling intensity of 3.2%, lower intensity depending upon distance between units or number of units to be sampled. The distance between plots is only 40 meters.

Modified Camp Unit System

In this system, one camp consists of four units of four tracts each (Annex 2). There are 20 plots in each tract of 300 x 300 m, the distance between plots being 60 meters. Therefore, the whole camp consists of 20x4x4 = 320 plots. Plot size remains the same as that of Camp Unit System. The whole camp covers an area of 5.4 x 5.4 square kilometers or 2,916 hectare, the maximum sampling intensity being 1.10%.

Unit System for Intensive Forest Inventory

The system has been modified by splitting the Modified Camp Unit System into separate units (Annex 3). The distance from center of unit to each tract is 500 meters, while plot lay-out in each tract remains the same as that of Modified Camp Unit System. Sampling intensity is, therefore, dependent on distance between the units, i.e. 2% if distance between the units is 2 km or 1.28% in case of 2.5 km distance. The system is used more in national- wide working plan inventories.

Cluster Sampling

The L-shaped cluster was developed by Dr.D.R. Pelz of the University of Freiburg in 1989. Each cluster consists of 9 plots on two sides, four plots on each side and one plot at the corner. One side of the cluster is in north direction and the other in east direction (Annex 4). The distance between plots is 100 meters and the distance between clusters is 4 km, sampling intensity being 0.056%.

This sampling design has been tested in northern and southern Thailand and found to be one of the most efficient design for the situation in Thailand. The system will be employed in the next national forest inventory, 1992–1996.

Apart from these inventory designs, selective sampling with fixed-area plots and point sampling using prism wage have been also tested, but they have not been in practice.

FOREST RESOURCES MONITORING

During the second national forest inventory, the Royal Forest Department established 34 permanent camps or 10,880 plots for continuous monitoring of forest resources : 8 camps in the North, 9 in the Northeast, 9 in the Central, and 8 in the South. Only two measurements were conducted before the plots were abandoned.

Table 1. Number of sample plots during the first and the second measurement (Päivinen 1991).

Region	1969–1973	1976–1979
North	2,394	1,673
Northeast	2,121	1,197
Central	1,857	573
South	1,668	722
Total	8,040	3,864

The results of these two measurements were used as a basis to estimate the total growing stock for the whole kingdom in 1981 (Thammincha 1982).

In terms of forest area estimation, more regular monitoring of forest land use has been conducted since 1961 using aerial photographs and satellite imagery with ground truth.

Table 2. Forest area of Thailand (Klankamsorn 1992).

Year	Forest area	
	square km.	% of total land area
1961	273,628	53.33
1973	221,707	43.21
1976	198,417	38.67
1978	175,224	34.15
1982	156,600	30.52
1985	149,053	29.05
1988	143,803	28.03
1989	143,417	27.95

Permanent plots have been recently established in the South as part of the permanent monitoring of tropical rain forests in ASEAN countries.

The weakness of forest resources management in Thailand is the lack of reliable data and information on growth and yield of the forests. Severe logging regardless of these parameters has brought the total logging ban in January 1989. It is essential that more regular and more efficient monitoring be adopted in regard to an increasing pressure over the very limited forest resources.

FUTURE OF NATIONAL FOREST INVENTORY

The Royal Forest Department has set the master plan for conducting national forest inventory during the years 1992 to 1996 with the following objectives.

1. To provide information on forest area by province.
2. To provide information on forest land use with reference to protection, encroachment, degradation, agro-forestry practices and timber production.
3. To provide information on stand structure and species composition of natural forest.
4. To determine volume of growing stock and increment.
5. To assess the status of forest resource, timber quality, pest and diseases.
6. To provide information on forest ecology.
7. To provide information on socio-economic conditions.

Special emphasis will be placed on the following activities.

1. Development of inventory operation more suitable to the forest conditions, e.g. designs, sampling intensity, permanent plot techniques.
2. Research related to multiple resource inventory, e.g. forest and forest stand management, social-economics, environmental impact assessment, case studies.
3. Strengthening the capabilities of forest inventory operations, e.g. provision of tools and equipment, orientation of inventory crew, cooperation among the agencies concerned, training.
4. International cooperation.

CONCLUSION

The development of national forest inventories of Thailand is significant during the last few decades. In terms of reliability and applicability of inventory results it can be said that inventory work in Thailand is not successful. More efforts must be devoted to inventory work in order to receive the most up-to-date and reliable data and information on forest resources which are very important in drawing up more efficient management strategies under the pressure from rapid economic growth.

REFERENCES

Boonyophas, C. 1988. Forest inventory in Thailand. Paper presented at the RAS/86/049 steering Committee Meeting, Bangkok, Thailand.

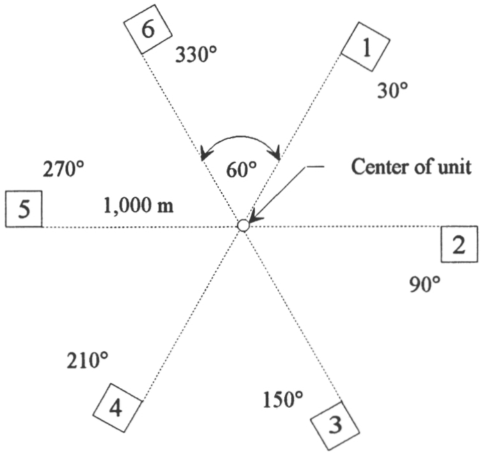
Kahkhong, S. 1987. Forest inventory in Thailand. Paper presented at AIFM Workshop on Forest Mensuration and Inventory, Sabah, Malaysia.

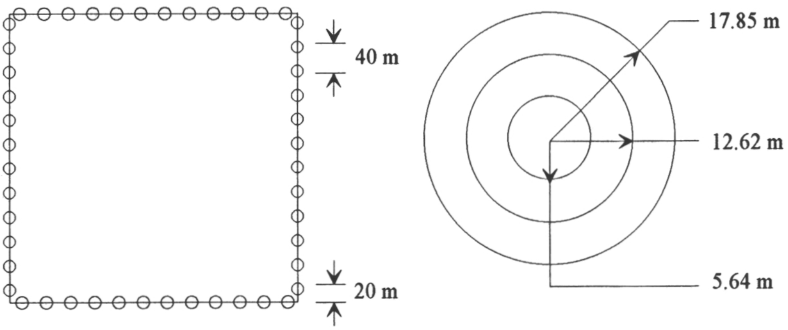
Klankamsorn, B. 1992. GIS and tropical forest monitoring. Proceedings of the IUFRO S4.02.05 Wacharakitti International Workshop, Pattaya, Thailand. p. 195–198.

Päivinen, R. 1991. Forest inventory in Thailand. Thai Forest Sector Master Plan. Working Document, Bangkok, Thailand. Mimeographed.

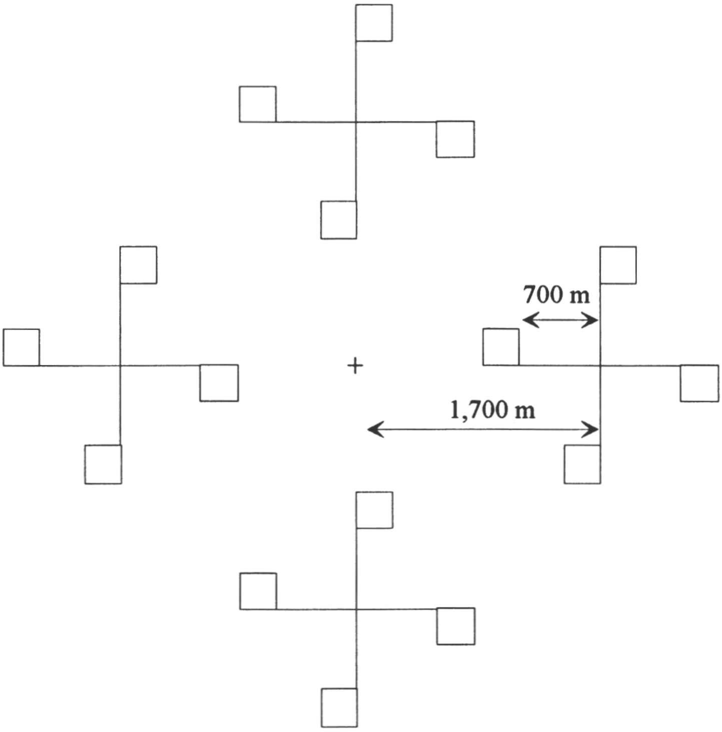
Thammincha, S. 1982. Thailand's forest resources data. FAO, RAS/78/010 Report. Bangkok, Thailand.

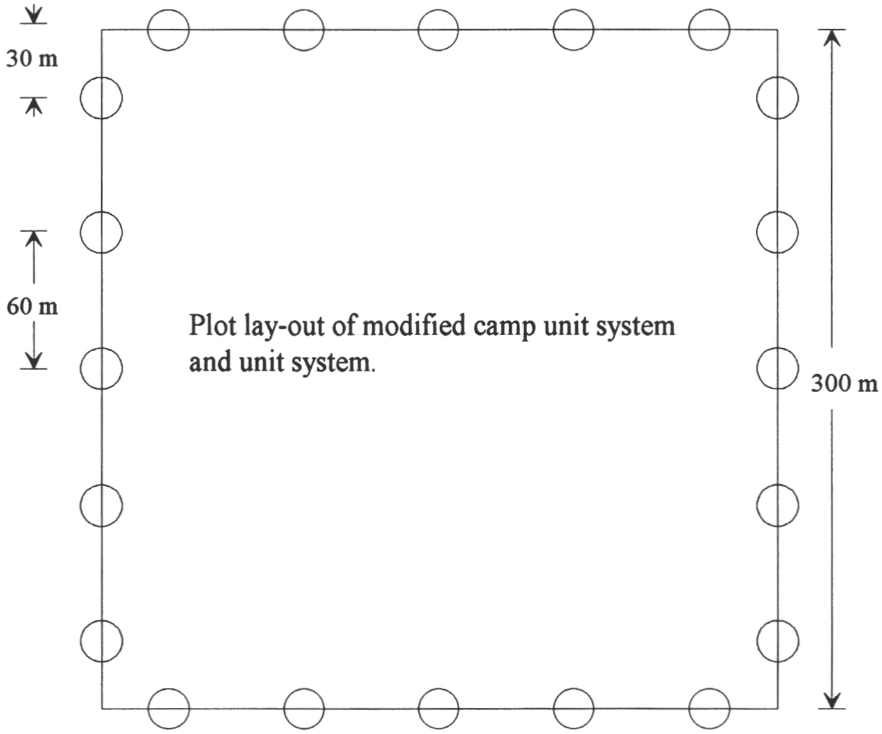
Thammincha, S. and Ruangchan, S. 1984. Forest inventory in Thailand. Country Report presented at FAO/UNDP Training on Application of Electronic Data Processing to Forest Inventory. Dehra Dun, India.



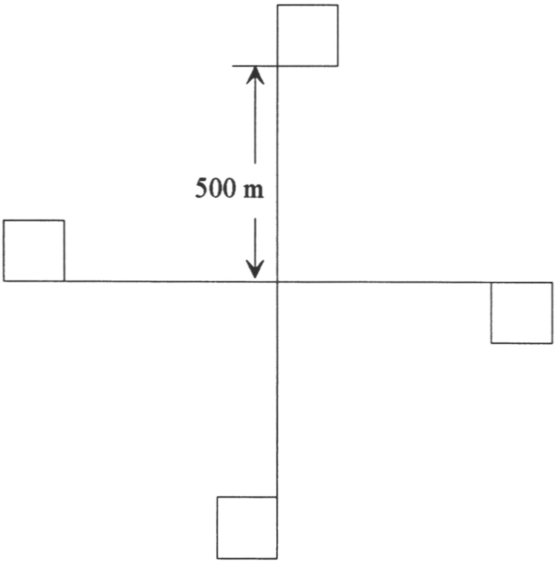


Annex 1. Camp unit system

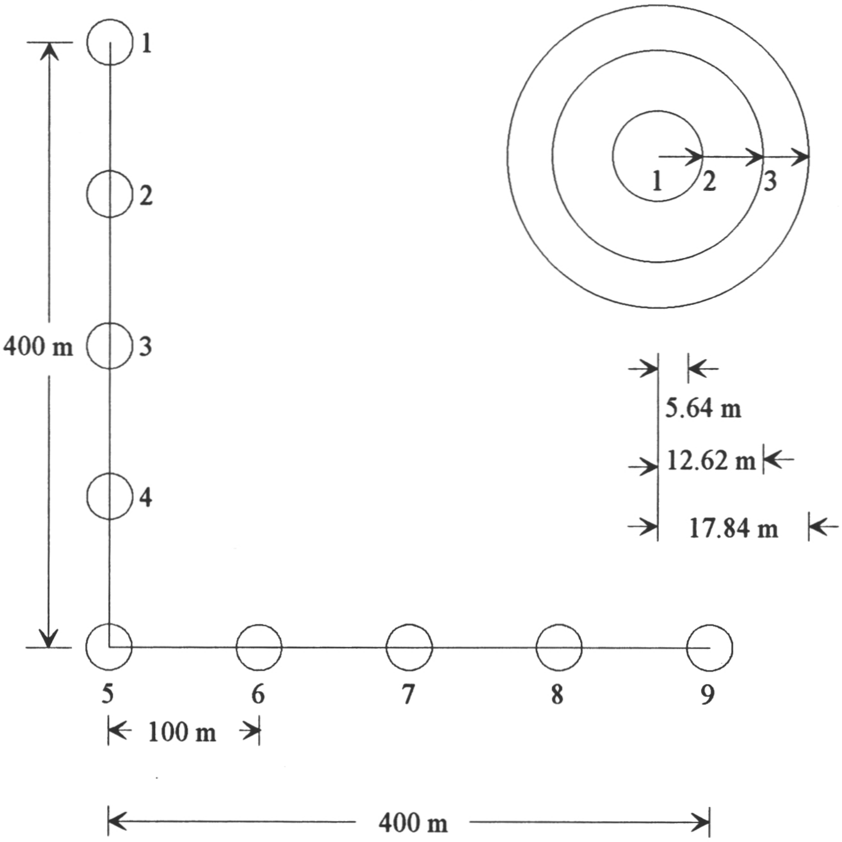




Annex 2. Modified camp unit system



Annex 3. Unit system



Annex 4. L-shaped cluster

FOREST INVENTORY AND MONITORING IN RUSSIA

Viktor V. Nefedjev
Head of “Lesproekt”
Moscow, Russia

Russia has considerable forest resources. Due to increasing involvement of forests into economic activities, also by participation of foreign investors, and arising of sharp ecological problems, appears urgent necessity in objective information about forest resources and their state, as they constitute of the most important components of natural environment.

The National Association “Lesproekt” of the Forest Committee by the Ministry of Ecology and Natural Resources is responsible for forest inventory and assessment in the Russian Federation. “Lesproekt” has widely developed network of affiliated branches all over the country, in Khabarovsk, Yakutsk, Irkutsk, Krasnoyarsk, Novosibirsk, Nizniy Novgorod, Voronezh, Saint-Petersburg, Moscow and other cities.

With the aim to periodically refine data about Russian forests once in five years is done national assessment of forest fund. The documentation set for forest fund assessment consists of four standardized assessment forms where information about quantitative and qualitative condition of forests is given. Form No 1 presents distribution of forest fund area by land categories, groups and classes of forest protection. In Form No 2 area and growing stock are divided by predominant species and age classes. In Form No 3 are given general data about forest fund including description of transport roads and forest fire management, data concerning afforestation and improvement fellings, and distribution of forest area by density and productivity classes. Form No 4 describes forests belonging to collective farms and state agricultural enterprises.

According to the last national forest assessment, on 1st January 1988 the total area of forest fund lands in Russia was 1.183 million hectares, including 771 million ha of forest area with total volume of growing stock equal to 81,6 billion cubic meters including 48,2 billion cubic meters of mature stands. Out of all the area of those lands 64 percent are covered with forests, 10% are other forest lands (non-closed forest cultures, cutting areas, fire-damaged forests, blanks), and 26% are non-forest lands, including swamps (12%), rocks, stony sites, sands (10%) and also grazing-grounds, hay-fields and arable lands (2%). Forests of the 1st Group occupy 26% of the forest fund area, and 2nd Group 5% and the 3rd Group the rest of the area. Forest division into groups is done according to the purposes and intensity of their use. Among the main forest-forming species coniferous are represented by 80% (including pine 18%, fir 13, larch 43, cedar 6, hardwood species by 3% (including oak 1%) and softwood species by 17% (including birch 13% and aspen 3%).

In Russia, depending on the intensity of forests use and their recreational significance, various inventory methods and technologies are applied. The highest level of accuracy must be secured by forest inventory in cutting areas. Stands which compose cutting fund of the corresponding inspection period are measured only by selective measuring-enumerative method (mainly by relascope plots) with accuracy as to the stumpage plus/minus 10%. Stands of intermediate cutting fund are measured with lesser accuracy but also with use of measuring-enumerative methods. All the other stands can be described with inventory methods based on aerial interpretation.

In order to obtain in a short period of time data about forests of Northern and North-Eastern regions which are specially sensitive to industrial influence there was developed and now widely used the technology of photo-statistical inventory for the taiga forests based on interpretation of small-scale (mainly 1:200000) space images in combination with middle-scale aerophotograps. This technology, as distinct from ground methods of statistical forest inventories, allows to receive forest maps showing spatial distribution of forest fund's land categories and groups (strata) of vegetation by sufficiently differential parameters – age groups, groups of stock concentration, predominant species, productivity, types of site conditions, and others. Each stratum, within the limits of its area, determined by space image, is described in detail. Reliability and accuracy of each stratum description is just as good as data of natural forest inventory by the lowest, the 3rd grade of forest management, which has the only advantage before photo-statistical inventory, that is ground organization of forest stand territory. Data of photo-statistical inventory allows to organize more rationally fire prevention service in these regions, to realize nature protective measures, and to reveal and manage forest stands of good prospects for industrial use. Photo-statistical inventory is a basic technology, which is used more and more widely with various modifications.

In order to reduce scope of labour-consuming field works in main logging areas (Siberia, European North) was developed and now in use technology of their repeated forest management on the basis of former inventory data and chamber interpretation of space survey data or aerophotographs of small scale.

For regions with developed deer-breeding exists technology of geobotanical inspection of deer grazing-grounds based on space survey data with determination of allowable number of animals for those grounds. For two years with this method were investigated about 3 million ha of deer grazing-grounds in the near tundra forest area. This technology was highly appreciated and has good prospects for further expansion.

National Association "Lesproekt" also uses a new technology for inventory of shrubwood vegetation of deserts and semi-deserts in Middle Asia and Kazakhstan, where vast areas of desert and semi-desert forests are used in agriculture for cattle breeding. Mean annual area of inventory works is about 1 million ha. Within the frame of this method is also done assessment of fodder resources in the desert grazing-grounds, that allows to develop plans for the use of desert forests as fodder base for cattle breeding, to elaborate recommendations for optimal, ecologically acceptable balance in damaged areas.

Forest inventory and management are large-scaled works with prolonged regularity. Prompt information about actual state of forest stands affected by fire, storms, etmopests and diseases, mass cuttings and pollution is obtained by a certain technology of discovery and assessment using remote sensing. This technology reveals changes in forest fund, including changes in land categories, composition and structure of forest fund and resources. Economic and ecological consequences of natural disasters are estimated and damage is calculated.

One of the urgent tasks in conversion of the Russian forestry branches into market economics is rational use of timber resources with minimization of their losses at cutting areas and by transportation as well as strict observance of cutting regulations and recommended technologies for felling works in accordance with silvicultural and ecological demands. For this purpose, the technology for examination of cutting areas with help of large-scale aerophotographs was developed; it has by now been in use for 15 years. Method is based on analytic-measuring interpretation of aerophotographs taken simultaneously at two scales – 1:1500 for detailed assessment of cutting area's condition and 1:8000 for estimation of parameters of the area actually cut. This technology is applied yearly at an area of 400000 ha of completed cutting areas. At the same time the basic logging territories are controlled with the help of space images in order to secure correct allocation of cutting areas and their correspondence to time/spatial parameters. As a matter of fact, application of those technologies presents by itself monitoring of forest utilization and management.

In regions of Russia with intensive forest use (Centre and West of European part, Southern Urals, the Volga region) where changes in forest fund take place with higher acceleration, the tasks of forest monitoring are realized through the technology of continuous forest management. Information basis for it is a subcompartment data bank of a forest industrial enterprise, which is formed from the data of basic forest inventory and renewed on the basis of complete or partial annual inventory of stands, which were exposed to this or that kind of industrial or natural influence. With a help of such data bank it is possible to solve tasks of continuous assessment and specification of forest resources, and of annual preparation of optimal plans for forest utilization. By this, the user receives necessary cartographic materials including compartment album of cutting areas for main and intermediate forest utilization. Subsequently, by use of cartographic data base for plan of cutting areas allocation, the forester can make necessary corrections.

On the basis of the use of remote sensing data the "Lesproekt" is planning further development of forest investigations and introduction, together with scientific-research institutions, of new technologies including forest inventory and assessment of forests contaminated by radionuclides, ecological management of forests affected by industrial pollution, assessment of damage caused to forests in the areas of gas and oil production, and some others.

Development of works on creation of cartographic and inventory data banks in combination with the use of space and ground technical means and methods will allow to start the all-Russian aerospace forest monitoring in order to secure renewal of data in automatic regime about forest fund, control of present state and use of commercial forests and their reforestation. This monitoring is to be inevitably included in international system of ecological resources monitoring. By now first steps in this direction are in progress. There is an agreement between the Finnish Forest Research Institute and the Russian National Association Lesproekt on joint ecological forest monitoring with use of ground and remote sensing methods in close-to-border regions of Russia and Finland including zones in the Leningrad region and Karelia, affected by industrial pollution. It is also planned to conduct joint works of the same nature at the Kola Peninsula and in the Northern Lapland.

FOREST INVENTORY, GROWTH AND YIELD STUDIES IN NIGERIA

John O. Abayomi
Chief Research Officer (Growth and Yield)
Forestry Research Institute of Nigeria
Ibadan, Nigeria

ABSTRACT

The national forest estate of Nigeria covers about 10 percent of the total land area, and comprises four fifths of savanna and one fifth of high forest. Forest plantations are much more productive than the natural vegetation types, but account for only 2 percent of the national forest estate. Previous inventories have been more or less localised with the exception of the indicative high forest inventory of 1973–1977, which was accompanied by a national vegetation/land use survey with Side Looking Airborne Radar.

Little has been achieved on the inventory of forest plantations but considerable information and data are available from sample plot studies, volume and yield table preparation, spacing and thinning trials as well as studies on site-productivity and stand dynamics. Problems confronting long-term forest inventory, growth and yield studies are highlighted in the paper and recommendations made for the future.

Keywords: Forest inventory, volume, yield

INTRODUCTION

The forest estate of Nigeria covers a total area of 96,518 km^2, which represents only 27 percent of the total forest cover and approximately 10 percent of the total land area. Four fifths of the forest estate is savanna woodland, and the remaining one fifth is high forest, which supplies the bulk of the country's timber. Although the total area of forest plantations in Nigeria is about 2,160.26 km^2 (Omoluabi et al 1990) or just about 2 percent of the national forest estate, emphasis has shifted over the last three decades towards the establishment of forest plantations because of the relatively low yields of the natural vegetation types.

Forest management in Nigeria is being carried out by 30 State Forestry Departments, with the Federal Department of Forestry (FDF) acting as the coordinating and monitoring organisation. The development of industrial forest plantations, farm forests and shelterbelts has been greatly enhanced by the World Bank Forestry Projects I and II together with the present African Development Bank Projects. These projects are handled by the Forest Management, Evaluation and Coordinating Unit (FORMECU) of the FDF. Forest inventory, growth and yield studies to aid forest management and planning in Nigeria have been carried out the Forestry Research Institute of Nigeria (FRIN), University Forestry Department, FDF, FORMECU and to a rather limited extent, State Forestry Departments. These studies are being reviewed in this paper with recommendations being made for the future.

HIGH FOREST INVENTORY

Nigeria, like other developing countries in the tropics, only recently started undertaking large-scale inventories in the high forest. Early efforts had been limited to discrete inventories for specific management and planning purposes. From the 1930's until the 1970's, the management of the reserved high forests had been based on the results of various reconnaissance and pre-investment forest inventories. Purely ground survey techniques were used for small forest areas, while large-scale forest inventories incorporated the use of aerial photography for forest stratification, vegetation mapping and stand volume estimation.

The systematic and stratified random sampling designs have usually been favoured in previous large-scale forest inventories. The systematic cluster sampling design was employed in the indicative high forest inventory of 1973–1977, which covered a total area of 1,330,100 ha (Sutter 1979). The inventory was done to determine the availability of merchantable timber, the degree of exploitation as well as quantity and quality of regeneration. Estimates of standing net volume per hectare in the surveyed forest reserves of different states are given in Table 1. Varying degrees of forest exploitation were observed in different states in Southern Nigeria. Whereas 85 percent of reserved forest in Cross River State was undisturbed, the corresponding percentage recorded for Ogun, Ondo, Oyo and Bendel States were 8, 43, 42 and 25 percents respectively.

Table 1: Area (in hectares) and standing volume per hectare of forest reserves surveyed in different States

States	Area of surveyed forest reserves (hectares)	Standing net volume (m³/ha)* 60 cm diam. and above	40 cm diam. and above
Ogun	151,200	44.38	66.46
Ondo	320,000	83.85	110.07
Oyo	118,200	59.04	80.55
Bendel	510,900	52.83	80.08
Anambra/Imo	37,100	15.01	22.05
Cross River*	192,700	114.36	159.91
Total	1,330,100	67.74	95.74

*Data computed from FAO (1979)
**Without Oban Group (415,700 ha).

Aerial photographs were not used for the indicative high forest inventory because the existing ones were outdated and new ones were too costly to acquire. However, Side Looking Air-borne Radar (SLAR) imagery was acquired and interpreted, and vegetation / land use maps produced at a scale of 1:250,000. These maps were later used to estimate the total area and timber content (by extrapolation from the indicative high forest inventory data) of the unreserved natural moist forest and derived savanna vegetation zones. The forested areas of some forest reserves not covered by the indicative high forest inventory were also determined with the aid of SLAR imagery. Further studies carried out with Landsat satellite under cloud-free conditions provided useful data and information for forestry and land use planning in the northern part of the country. The analysis of the Landsat imagery indicated that 0.8 million hectares of reserved woodlands in the Guinea Savanna Zone had the potential for forest plantation development.

Tree Increment Studies

Studies of changes in the growth and structure of forest stands are necessary for effectively managing the high forest on a sustained yield basis. In order to improve the concentration and representativeness of tree increment plots in Nigeria, one hectare permanent monitoring plots were recently established from the systematic cluster sampling network of the indicative high forest inventory. The permanent monitoring plots were recently established from the systematic cluster sampling network of the indicative high forest inventory. The permanent monitoring plots measure 250 metres by 40 metres, and all trees with dbh of 40 cm and above are to be measured. The central 0.25 ha and 0.2125 ha strips of these plots are to be used for measuring trees with dbh not less than 20 cm and 5 cm respectively.

The established permanent monitoring plots are supposed to be remeasured every two years, but after the first and second assessments of this network of plot, no further assessments had been carried out because of financial constraints. Interesting results have however been obtained by Ojo (1990) from tree and soil data collected from the first two assessments of 80 permanent monitoring plots distributed in five sites which represent major climatic, geological and soil types within the rain forest zone. Data analysis indicated that soil fertility tends to increase and mean annual rainfall tends to decrease from the most easterly site (Oban) to the most westerly site (Omo). Although the five sites appear to be different from one another in terms of species composition, they are similar in terms of diameter and basal area distributions and in the representativeness of individual species.

The number of marketable timber species also varies between sites, while for each tree species, mean annual diameter increment is variable between dbh classes and sites. Considering all five sites together, the average mean annual diameter increments (cm/tree/yr) are estimated from the results obtained by Ojo (1990) to be 0.303, 0.416 and 0.504 respectively for trees in the 5–20, 20–40 and 40–60 cm dbh classes. The corresponding ranges of average mean annual diameter increments are 0.255–0.404, 0.325–0.597 and 0.379–0.678 cm/tree/yr. Annual diameter increment therefore appears to have a positive relationship with stem dbh.

FOREST PLANTATION INVENTORY

Unfortunately very little has apparently been done in Nigeria as regards the inventory of the forest plantations established by the State Forestry Departments. The only forest plantation inventories carried out in the recent past were those by FORMECU on the few large scale plantations established under the World Bank and African Development Bank–assisted projects in four States. The results of these inventories are yet to be published. FRIN has not carried out any State forest plantation inventory, but in February to May 1980, FDF carried out an inventory of *Gmelina arborea* plantations established from 1966 to 1975 in the Omo Forest Reserve, Ogun State. The survey covered 5,100 ha with a net plantation area of 4,400 ha.

The above-mentioned inventory was done to reassess the conditions of the old Gmelina plantations and to estimate the volume available for pulpwood production. The plantations were assessed along lines cut at 300m intervals. Four classes of density i.e. good, medium, poor and zero stocking were assessed subjectively in relation to what was considered as fully stocked. Trees were enumerated in circular plots of 12m radius.

The inventory results (Sutter and Okefiena 1981) provided the following data in respect of each plantation block from P 1966 to P 1975 - area of plantation in hectare and stocking volume in cubic metre as derived by plot means and by yield function; net area in hectare by site index classes; net area in hectare by density classes, and predicted future stocking volumes for the years 1980 to 1984.

FOREST PLANTATION GROWTH AND YIELD STUDIES

Although the total area of existing forest plantations is only 2 percent of the total national forest estate, considerable amount of data and information has been collected from growth and yield studies. Sample plot data have indicated the levels, trends and variations of the growth and yieldsof forest plantations of economic timber and pulpwood tree species in different sites.

The standing timber volumes of some forest plantation PSP's are presented in Table 2 for comparison with Table 1. If all the economic timber species in each PSP are considered it is apparent that the plantation PSP's tend generally to have much greater standing timber volumes per hectare than the corresponding estimates for the natural high forest. It should also be noted that the total standing volume for trees of 10 cm dbh and above rarely exceeds 240m3/ha (Kio 1978) for the natural high forest. The annual increment of timber volume above 40 cm dbh range between 1.14 m3/ha/yr and 8.34m^3/ha/yr for the plantation on PSP's as compared with the often quoted increment of 2 to 3 m^3/ha/yr for the high forest. Unfortenately, State forest plantations tend to have poorer stockings and therefore lower yields than plantation PSP's due to inadequate silvicultural treatment caused largely by financial constraints.

The rapid growth of forest plantation species has been confirmed by the results of studies carried out by Lowe (1970), which showed that in 10 years, the final crop trees of *Terminalia ivorensis*, *Tectona grandis*, *Triplochiton scleroxylon* and *Nauclea diderrichii*, without thinning and on good sites, exceed dbh of 32, 28, 21 and 20 cm respectively. Lowe's findings were on the basis of 50 final crop trees per ha for *T.ivorensis* and 125 for the other species and planting espacements of 5.5m, 2.4m, 3.7m and 3.7m respectively. The PSP data for *T. ivorensis* indicates that average periodic annual diameter increment is about 0.66 cm between the ages of 31 and 57 years at Gambari (Oyo State) and about 1.33 cm between the ages of 6 and 25 years at Sapoba (Edo State).

Table 2: Standing volumes of Plantation Permanent Sample Plots in the High Forest Zone

PSP No.	Location	Species	Age (yrs)	Standing	volume	(m^3/ha)
				60 cm diam. and above	40 cm diam. and above	10 cm diam. and above
6	Omo	Nauclea	62	0.0	173.4	224.3
7	Omo	Nauclea	63	37.2	270.9	289.5
12	Gambari	Terminalia	57	76.8*	206.6*	268.1*
17	Omo	Nauclea/ Meliaceae	54	91.9	292.5	338.4
18	Omo	Nauclea	54	21.3	217.7	239.9
116	Olokemeji	Teak	55	48.1	183.6	289.4
117	Olokemeji	Teak	63	36.3	470.3	470.3
144	Sapoba	Triplochiton	50	58.2*	104.0*	302.0*
145	Sapoba	–do–	50	24.1	56.9*	228.4*
146	Sapoba	Cedrela	54	126.3	450.5*	472.2*
147	Sapoba	Cedrela	54	234.4*	433.2*	456.0*

* Volume includes that of other economic timber species present.

Yield tables have been prepared for *Tectona grandis* and *Gmelina arborea* in the high forest zone of Nigeria, giving the predicted yields of well-stocked plantations of both species in terms of total crop volume production down to a minimum dbh of 10 cm for different age and site quality classes. Maximum MAI has been predicted to range from 13.1 to 23.9 m^3/ha/yr at age 10 for *Tectona grandis* and from 19.7 to 39.9 m^3/ha/yr at age 8 for *Gmelina arborea*. The poorest site quality classes of these two plantation species even appear to be more productive than the high forest.

The superiority of artificial regeneration over natural regeneration is strongly evident in the savanna zones. Productivity studies carried out by Jackson and Ojo (1971) indicate that the MAI of natural woodland in the northern Guinea Savanna zone of Nigeria varies from 0.35 to 1.05 m^3/ha/yr for fuelwood production. Lowe (1982) observed that the savanna woodlands of Nigeria have on the average between 10 and 20 m^3 of wood per hectare, most of which is suitable for poles and fuelwood. Most savanna forest plantation species can be expected to yield 14 m^3 or more per ha per year (Jackson and Ojo 1971), MAI ranging from 1.75m^3/ha/yr for very poor quality neem plantations to over 42m^3/ha/yr for fast growing Eucalypts on the Jos Plateau. Adegbehin et al (1985) observed that *Pinus caribaea* on an average savanna site attains a top height of 23.4m at age 20 and a maximum MAI of 24.2 m^3/ha/yr at age 30.

Spacing and Thinning Trials

Results from spacing trials of *Tectona grandis, Terminalia* species and Pinus species in the high forest zone have shown that planting espacement tends to strongly influence mean dbh, stand basal area and stand volume production. Mean height growth is sometimes influenced by planting espacement, while top height appears to be insensitive to planting espacement. Thinning trials of *Tectona grandis* have indicated that stem diameter increment is more sensitive to thinning treatment than height increment. While diameter increment tends to increase thinning intensity, medium thinning intensity tends to produce greater height increment than an extremely low or high thinning intensity.

Residual stockings of 800, 600, 400 and 300 stems per hectare have been recommended for Teak plantations on average quality sites at the ages of 5, 10, 15 and 20 years respectively (Abayomi et al 1985). Lowe (1976) has observed that the thinning of Teak stands may be delayed for 10–15 years after planting without any appreciable loss of increment by the final crop trees. He however recommends very heavy thinning (down to well below 20 m2/ha) so as to accelerate the growth of the final crop trees. Ten years after Lowe's final assessment of his Teak thinning trial plots at Ibadan (Oyo State), Nwoboshi (1985) carried out another assessment on the same plots and observed that the mean tree in the heavily thinned plots had over the ten-year interval increased its diameter by 68 percent, and its basal area and volume by over 60 percent. The yield of merchantable wood was also tripled by thinning.

Site – Productivity Studies

Interesting results have been obtained from site-productivity studies on *Tectona grandis, Terminalia superba, Gmelina arborea* and *Pinus caribaea*. Using data from 168 temporary sample plots of 3 to 9 years old *Tectona grandis* plantations in South-western Nigeria, Akinsanmi (1985) found through multiple regression analysis that volume growth was, with varying degrees of reliability, significantly correlated with rainfall, texture, organic matter content and soil pH. However, soil pH (in CaCl2) at 0–15 cm layer and sand/clay contents at 60–90 cm layer were the only variables which showed significant linear relationships ($p<0.05$) with site index in the study of 72 temporary sample plots of 9 to 21 years old *Tectona grandis* plantations in the dry high forest area of Nigeria (Akindele 1990). Five years old *Terminalia superba* at Ore (Ondo State) grew much better in height and diameter than at Gambari and Ibadan (Oyo State) because of the higher levels of clay content, organic matter, total nitrogen, base saturation, cation exchange capacity and basic cations in the Ore soils (Aluko 1977).

The productivity of *Gmelina arborea* varies widely according to site qualities and climate. In Kaduna (Guinea savanna) a top height of 20m and a MAI of 19.8m^3/ha/yr are attained at age 10 on an average site, compared with 22m and 39 m^3/ha/yr respectively for a 10 years old site Quality I stand at Omo (rainforest). MAI increases to 23 m^3/ha/yr at age 15 for the average site in Kaduna, and to 31.3m^3/ha/yr for site Quality I at Omo. *Gmelina arborea* is tolerant of a wide variety of soils and less site demanding than *Tectona grandis*. Latest studies indicate that *Gmelina* plantations respond significantly to effective soil depth, percentage gravel, pH, calcium and potassium contents of soils, and these features could be used for predictive purposes (Kio et al 1990).

The effects of soil depth, percentage gravel content and water capacity of soils on the growth of 7 years old *Pinus caribaea* stands at Afaka in the Northern Guinea savanna were studied by Ezenwa (1985). He found that effective soil depths were significantly correlated with tree height and basal area, while mean percent gravel content was negatively correlated with them.

Studies on Stand Dynamics

The latest development in forest plantation studies is in the area of stand dynamics, in which mathematical models are being used to describe the present conditions and changes with age of stem diameter distributions. The Weibull distribution function has been found to be quite suitable for describing the stem diameter distribution of stands of *Meliaceae* species in the rainforest zone and *Eucalyptus* and *Pinus* species in the savanna zone.

Studying plots of *Eucalyptus* species aged between 3 and 16 years and those of *Pinus caribaea* aged between 4 and 29 years, Adegbehin (1985) was able to accurately describe stem diameter distributions with the 3 -parameter Weibull distribution function as from the minimum age of 4 years for *E.cloeziana* and 6 years *E. tereticornis* and *P.caribaea*. Moreover the Weibull parameters of the stem diameter distributions of new stands could also be reliably predicted with the aid of stand attributes and site factors for *E. cloeziana* and *E. tereticornis* as from the age of 4 years. However, this was impossible until the age of 10 years for *P. caribaea*. Attempts are now being made to apply the 3 -parameter Weibull distribution function to stands of other forest plantation species in the rainforest zone, namely, *Nauclea diderrichii, Terminalia ivorensis* and *Triplochiton scleroxylon*. This is to broaden the spectrum of information and data on the stand dynamics of forest plantation species in Nigeria.

CONCLUSION

Problems confronting long-term inventory and monitoring of Nigerian forests include illegal/uncontrolled exploitation, inadequate replication of samples, imprecision of silvicultural treatments, prohibitive costs of field operations and of acquiring sophisticated equipment (Kio et al 1985). The National Forest Resources Assessment of Nigeria, the plan of which was developed about five years, is yet to take off the ground because of financial constraints.

Growth and yield studies of forest plantation species in Nigeria are so far limited in scope, and lack coordination and co-operation between the various forestry organisations in the country. Permanent sample and research plots of individual species are rather few, of limited age, site and stocking ranges, and subject to illegal felling or destruction by fire. State forest plantations which are to serve as data source for growth and yield studies, are usually poorly maintained and managed. An adequate network of spacing/thinning trial plots, crop plots and continuous forest inventory plots is urgently needed for carrying out studies on site-productivity and stand dynamics, as well as developing accurate growth and yield models.

Financial, technical, administrative and socio-economic problems confronting forest inventory, growth and yield studies in Nigeria have to be seriously tackled before any appreciable achievements can be made. Future national forest inventories are likely to require the financial and technical support of bilateral or multilateral organizations. However, the various forestry organisations in the country should co-operate in the planning and execution of forest inventory, growth and yield studies, and also ensure the effective maintenance and management of all forest stands.

REFERENCES

Abayomi, J.O., Ekeke, B.A. and Nwaigbo, L.C. 1985: Some preliminary results of Teak thinning trials in Nigeria. Proceedings of the 15th Annual Conference of the Forestry Association of Nigeria, Yola, 25th–29th November, 1985.

Adegbehin, J.O. 1985: Growth prediction in some plantations of exotic tree species in the Northern Guinea and Derived Savanna zones of Nigeria. Ph.D Thesis, Department of Forest Resources Management, University of Ibadan, Ibadan.

Adegbehin, J.O.,Okojie, J.A., Nokoe, S. and Omijeh, J.E. 1985: A preliminary growth study of *Pinus caribaea* in the Northern Guinea and Deprived Savanna zones of Nigeria. In proceedings, 15th Annual Conference of the Forestry Association of Nigeria, Yola.

Akindele, S.O. 1990: Site quality assessment and yield equations for Teak plantations in the dry forest area of Nigeria. Ph.D Thesis, Department of Forest Resources Management, University of Ibadan, Ibadan.

Akinsanmi, F.A. 1985: Effect of rainfall and some edaphic factors on teak growth in southern Nigeria. *Journal of Tropical Forest Recources,* vol. I No. I, pp. 44–52.

Aluko, A.P. 1977: Nutrient status and growth of *Terminalia superba* in plantation. Paper presented at the 7th Annual Conference of the Forestry Association of Nigeria, Kano.

Ezenwa, M.I.S. 1985: Effects of some soil physical properties on growth of *Pinus caribaea* in Northern Guinea Savanna area of Nigeria. In proceedings, 15th Annual Conference of the Forestry Association of Nigeria, Yola.

Jackson, J.K. and Ojo, G.O.A. 1971: Productivity of natural woodland and plantations in the Savanna zones of Nigeria. *Nigerian Journal of Forestry*, vol. I, No. 2, pp. 57–60.

Kio, P.R.O., 1978: Stand development in naturally regenerated forest in southwestern Nigeria. Ph.D Thesis, Department of Forest Resources Management, University of Ibadan, Ibadan.

Kio, P.R.O., Abayomi, J.O. and Okorie, P.E. 1990: Growth and productivity of *Gmelina arborea* in West Africa. Invited paper at the symposium on the Productivity and Utilization of *Gmelina arborea* in West Africa. Department of Forest Resources Management, University of Ibadan, Ibadan.

Kio, P.R.O., Ola-Adams, B.A. and Abayomi, J.O. 1985: Inventory and monitoring of tropical forests–The Nigerian experience. Proceedings of the IUFRO Conference on Inventorying and Monitoring Endangered Forests, Zunch, Switzerland.

Lowe, R.G. 1971: Some effect of stand density on the growth of individual trees of several plantation species in Nigeria. Ph.D Thesis, Department of Forest Resources Management, University of Ibadan, Ibadan.

Lowe, R.G. 1976: Teak (*Tectona grandis* Linn. f) thinning experiment in Nigeria. *Commonwealth Forestry Review,* vol. 55, No. 3, pp. 189–202.

Lowe, R.G., 1992: Forestry and land reform in Nigeria. *Nigerian Journal of Forestry*, vol. 12, No I, pp. 58–63.

Nwoboshi, L.C. 1985: Growth of Teak (*Tectona grandis* L.F.) ten years after thinning. *Nigerian Journal of Forestry*, vol. 15, No. 1,2, pp. 76–79.

Ojo, L.O. 1990: High forest variation in southern Nigeria. Implication for management and conservation. Ph.D. Thesis, University of Wales, Department of Forestry and Wood Science, Bangor.

Omoluabi, A.C., Ogundare, L.G., Onwuka, S.O. and Martin, V. 1990:Nigeria–Forest plantation development, FORMECU, Federal Department of Forestry, Ibadan.

Sutter, H. 1979: The indicative inventory of reserved high forest in southern Nigeria 1973–1977. FAO Technical Report, FO: NIR/71/546.

Sutter, H. and Okefiena E.A.O., 1981: An inventory of the old *Gmelina arborea* plantations in the Omo Forest Reserve of Ogun State. UNDP/FAO/Nigeria. FO: NIR/77/008. Project Working Document No.9.

GLOBAL MONITORING OF FOREST RESOURCES

NATIONAL INVENTORIES SERVING GLOBAL MONITORING OF FOREST RESOURCES

Klaus Janz
Senior Forestry Officer
Forest Resources Appraisal and Monitoring
Forest Resources Division
FAO
Rome, Italy

ABSTRACT

National forest inventories serve the purpose of national planning and monitoring with regard to the utilization of forest and related resources. They must be designed to fit the conditions of the country in which they are conducted. These conditions are so different between countries and regions, that variables studied as well as definitions and classifications chosen will always differ between countries.

Information from global forest resources assessments is primarily used in the formulation of development strategies and in setting priorities for international cooperation on forestry problems. To be meaningful global assessments require a common framework of terminology and classifications as well as availability in all countries of essential information. An obstacle to using national inventories in global studies is that there is far from complete coverage with reliable essential information. In particular there are few cases of comparable repeated inventories.

It is the UN system with its well established country contacts that is using national inventories to build up global information on the forest resources. Two of the three approaches currently used in global forest assessment are, at least in part, based on existing country information.

The assessment for the industrialized countries relies entirely on information existing in the countries. Questionnaires and a net of country correspondents are used to collect the information. Even in this country group the completeness and the quality of available information are severe limiting factors for the quality of the results.

One of the two approaches used in the assessment of tropical forests is based on a systematic review of existing information available in the countries. The base information is still very incomplete in many countries. This is in particular the case with multi-date information. Therefore country capacity building is an essential element of the future forest resources assessment programme.

Keywords: Global forest monitoring, national forest inventories, definitions, classifications

BACKGROUND

One of the outcomes of UNCED is a renewed attention to forest resources assessment. This is quite evident among others in Agenda 21. In chapter 11 “Combating deforestation” one of the four programme areas has the title **“Establishing and/or strengthening capacities**

for the planning, assessment and systematic observations of forests and related programmes, projects and activities, including commercial trade and processes". In this programme assessment and systematic observations are put in the context of long-term planning, evaluating effects and rectifying inadequacies. The objective is set "to strengthen or establish systems for the assessment and systematic observation of forests and forest lands with a view to assessing the impact of programmes, projects and activities on the quality and extent of forest resources, land available for afforestation, and land tenure, and to integrate the systems in a continuing process of research and in-depth analysis, while ensuring necessary modifications and improvements for planning and decision-making..." Most of what is said is applicable to both national and global assessments and gives a renewed importance to the topic of this symposium.

Agenda 21 also puts the collection of information in the context of "sustaining the multiple roles and functions of forests, forest lands and woodlands". A number of countries have developed approaches to adapt their national and local forest inventories to a wide range of needs in this sense. However, on the international level there is as yet little of common concepts and terminology conventions. Concrete steps on the international level to develop common concepts and to include biomass as well as non-wood goods and services have been taken by the Joint FAO/ECE Agriculture and Timber Division in Geneva for the industrialized countries. The second round of forest resources assessments with the wider scope is now about to be published. Obviously, the success is limited by what the countries can contribute.

The current tropical forest resources assessment of FAO is focusing on forest cover area and area change, which are important environmental parameters. On biomass it will include some rough estimates, given the scarcity of reliable information on this subject. Other environmental parameters are only marginally covered with the exception of protected areas which have been studied more thoroughly.

UNEP and FAO will jointly arrange an expert meeting on the inclusion of environmental aspects in future forest assessments in November this year. This meeting will identify issues, propose parameters and indicate methods to assess them. The results of the meeting will be an input to a FINNIDA/FAO meeting of general forest inventory experts to be held in Kotka, Finland in May next year in preparation of the next global forest resources assessment. The present symposium fits extremely well into this process with regard to its theme and the time chosen. I expect a strong input of ideas from it.

During the process of preparing UNCED the term "monitoring" has become politically sensitive as it can be interpreted as encroachment on the sovereignty of countries - in particular developing countries. The official UNCED term has become "systematic observation".

WHY NATIONAL AND GLOBAL INVENTORIES

Why national forest inventories and why global monitoring of forest resources? Who are the users and which are the uses of the information gathered? In which situations do the users need information about the forest resource? If we first give these questions some thought we may then be in a better position to tell how the two levels of inventory can cooperate.

National Forest Inventories

National forest inventories serve national planning and monitoring with regard to the utilization of forest and related resources.

Planning in this context includes the identification of problems, the formulation of policies to attack them and the implementation planning on the high (province or country) level.

Monitoring means to observe developments in general and to assess the impact of various policy measures in particular. The result of monitoring may be that a need is identified to modify policies or their implementation.

National forest inventories make sense only if there is an institutional structure capable of formulating national forest policies, well linked to overall national policies and a power to implement them. Where these conditions are not fulfilled countries should not be encouraged to conduct national forest inventories.

The following examples may illustrate the diversity of planning situations that occur in national inventories:

Indonesia: For the current national forest inventory project the following questions have been formulated:

(1) How much and where are the wood production forests, virgin and logged; what changes have taken place in their areas in the recent past and what are the likely trends?
(2) What is the wood supply potential, by main utility class under alternative management systems?
(3) What is the state of forest cover nation-wide and where are the critical areas, needing urgent rehabilitation or protection measures?

Behind these questions is among others a nation-wide land-use planning effort which is facing the need to identify suitable forest land for controlled conversion into agricultural use.

Peninsular Malaysia: Earnings from timber export are important to the country. Since only small areas of virgin forests are left, future timber harvesting will have to come almost exclusively from logged-over forests. In which regeneration status are these forests now? What is their long term supply potential and how can the supply be distributed over time? A sub-national inventory covering Peninsular Malaysia is under way, in which important elements are:

(1) Site classification
(2) A classification reflecting the occurrence of previous logging and the time since.
(3) Growth and yield studies that can be related to the above sites and development phases (research on the species-size dynamics in logged-over forests on different sites).

Colombia: In the Kotka meeting of 1987 that laid the ground for the current global forest resources assessment Mr. Molina reported inter alia on newly emerging needs for inventory information. I have selected some examples:

(1) Intensify the production of the tropical rainforest e.g. by integrating agriculture, silviculture and sheep production
(2) Study the structure and dynamic functioning of the tropical rain forest ecosystem (see the related topic 3 in Malaysia)
(3) Studies of flora, especially in intervened areas

The few examples show that there is a great diversity of planning situations on the national level. These require an array of variables to assess and methods to use, different from country to country.

Global Assessments

In the case of global forest resources assessments there is less of a consolidated opinion on who the users are and which the uses. The following is a tentative review as seen from the FAO outlook:

Global assessments of forest resources were a major issue on the agenda for at least the three first Conferences of FAO, held in the years 1945–47 (the Conference is the highest decision-making body of FAO). The first World Forest Inventory, published in Unasylva 1948, was put in a context that is best described by the following quotations and extracts: "The whole world is suffering from shortages of forest products". Fuel and timber as well as the protective and social functions of forests are the main products. The latter "are factors affecting world supplies of wood". Unwise harvesting, clearing for agriculture, excessive grazing, repeated fires are the primary threats to forests. "In a study of the forest resources of the world, determination of the extent of productive areas and, above all, determination of the rates at which they can produce wood in perpetuity are far more important than the estimation of present volumes of standing timber". Given this background description quite logically two focus areas were derived; (i) "whether or not the world's forest resources are sufficient in extent and in productive ability to sustain present and prospective needs for their products" and (ii) observation of change, manifested in the intention to repeat the assessment periodically with this particular goal in mind and in an emphasis on growth and drain assessment.

Experience has taught us that repeated global assessments do not give us a usable change assessment and that comparable national growth and drain estimates up to now exist only exceptionally. However the need for such information has only increased – to the degree that it is often referred to as something new.

More specifically we do currently see the following three groups of uses/users for information on the global level:

Creating awareness about state and change of forest and related resources. The users are the general public via media, schools, textbooks and similar. Here we must assume that the general public often gets a distorted view since there are intermediates, and these intermediates may give misinterpreted or incomplete messages or even have an interest to give the message a certain bias. Establishing good relations with the "intermediates" and learning their rules becomes, therefore, a part of our job.

Planning and monitoring. The users are planners and policy makers in the fields of forestry, environment and development on the international level. They will belong to international or national organizations engaged in international cooperation. The monitoring element is to show the effects of past and ongoing activities. Accuracy and geographic resolution must be adapted to the needs on the international level. The present understanding is that this means good accuracy in the important parameters on the sub-regional level (to indicate the size: there are 12 subregions in the tropical region). Reporting should be on the country level, but the objective is not to give information with sufficient accuracy for national planning.

Research. There is a legitimate request for information raised by the research community which should be met by global monitoring. It is understood that the principal uses are in research on (1) the supply potential in a wide sense (i.e. the question to what extent forests and related resources sustainably can meet the needs of people) and (2) processes such as deforestation, forest degradation, climate change and the driving forces behind them.

It belongs to the picture that the "users" with which FAO gets in contact and who express views regarding information needs mostly are either other international organizations, institutes, consultancy firms and technical writers who themselves are intermediates. There is a general lack of user communication with the planners, decision makers and researchers who should perhaps be the primary target group. Hence our uncertainty.

I think it is right to say that the uses that we can discern are chiefly concerned with the preparation of regional and global strategies to attack regional or global problems. To this end the problems must be detected and quantified, the processes affecting them must be understood and the changes monitored. We can note that, compared with the national level, the number of issues that are subject to regional or global concern and activities is very limited.

Typical questions that are being addressed by global monitoring are:

(1) What is the area of forest by country? – This is background information
(2) What is the global deforestation rate? – Also background information
(3) How are deforestation and forest degradation distributed into climatic zones? – Such information, preferably linked with other relevant information, contributes to analyzing driving forces and can help in finding general remedies
(4) What is the pattern of land use changes (e.g. for which uses are forests cleared)? –Same use as (3)
(5) Where and when do particularly rapid and severe changes take place? – Such information is needed for operational planning focused on critical areas and using specific measures
(6) What is the long term wood supply potential? – Since markets are highly international, national governments, industrial and trade organizations as well as economic research show a major interest in this type of information. It is used for the adaptation of national/sectoral policies to the international situation. Comprehensive information has so far only been collected from industrialized countries. The necessary calculations have been made by the countries themselves. I assume it will stay that way since the factors influencing wood supply are very complex and country specific.

NATIONAL INVENTORIES SERVING GLOBAL MONITORING

Obstacles and Opportunities

For the purpose of global forest resources assessment and monitoring there must be one common framework of definitions and classifications. This should allow for comparability between countries and for continuity in time series. (Ideally the assessment methods also need to be common, but this is so far from realities of life that we may just note for the time being that there will be greater or smaller defects in comparability as long as the methods used for forest inventories are not the same.) Moreover the information in global inventories is only meaningful if complete country coverage can be achieved for the essential parameters so that regional aggregates can be derived, in other words it must cover all countries of a given group.

National inventories serve national purposes of planning and monitoring as we have noted above. The variables studied as well as definitions and classifications chosen differ widely between countries. This is an obstacle to the use of national inventories in the global context. International organizations should endeavour to develop broadly acceptable concepts, standards and classifications. But given the wide range of political, historical and natural environments in which such inventories are conducted we must accept that there may be something sound about the disharmony. What is realistic is to work for a better understanding of other countries' concepts. Such work should produce the possibility to translate between the categories distinguished in different countries. In particular it should produce the possibility of translating country information correctly into the common framework used in the global context. Clearly and rightly countries expect FAO to play its role in this context.

The requirement of completeness is far from being fulfilled. The tropical forest resources assessment 1990 made a thorough search for "existing reliable information" from the tropical countries. Table 1 is an extract from the FORIS (Forest Resources Information System) data base held at FAO and illustrates how incomplete the coverage is in the tropical countries for various types of information. An in-depth review team concluded in April this year that in the foreseeable future there are no prospects of collecting growing stock information from this group of countries. The forest resources assessment for the industrialized countries also encountered gaps in "essential information" although less serious.

Table 1: Availability of forest resources data at national level for tropical countries (Evaluation from the Forest Resources Information System - FORIS)

Region (Number of countries under assessment)	Number of countries with forest resources data at national level						
	Forest area information (No. of assessments and reference years)			Forest conservation and management	Forest plantations	Volume and biomass	Forest harvesting and utilization
	one assessment		more than one assessment				
	1980	before 1980					
Africa (44)	15	13	2	7	5	2	4
Latin America & Caribbean (43)	21	9	9	12	6	4	4
Asia & Pacific (17)	5	1	11	9	9	8	7
Total (104)	**41**	**23**	**22**	**28**	**20**	**14**	**15**

Note: The first three columns are additive. This implies that from 41+23+22=86 countries forest area information has been retrieved that could be used in the assessment, while from the remaining 18 countries such information could not be retrieved.

A facilitating factor is that information needs on the global level are less detailed than national needs in terms of number of variables studied and classes distinguished. When studying users and uses we noted that the number of issues that are subject to regional or global concern and activities is very limited compared with the national level.

Solutions used at Present

Industrialized countries: The Joint FAO/ECE Agriculture and Timber Division in Geneva is presently finalizing its forest resources assessment 1990 for the industrialized countries: The assessment relies on information existing in the countries (except for cases where gaps in "essential information" are filled with information extracted from other sources or with secretariat estimates). Questionnaires are used to collect the information. Considerable work is laid down in cooperation with working parties and expert groups to agree on data content and the necessary definitions, classifications and guidelines. Two major new portions of information have been added in the last ten years. They are concerned with biomass and non-wood goods and benefits. In these cases consultants have helped to develop concepts, questionnaires and guidelines. An important element in the process is a net of country correspondents with the following functions:

(1) Assist in collecting the information asked for by engaging relevant national sources
(2) Make sure that the information is complying to the standard definitions and guidelines.
(3) Assist with user communication. In particular make sure that results reach the right users and that users needs and viewpoints are considered in the planning of new assessments.
(4) Based on the knowledge of the global assessment assist on the national level in analyzing

results of these assessments. Based on the knowledge of national conditions assist the secretariat in analyzing country information

Obviously much depends on the personal interest of the country correspondents and on the support they receive in their home countries. In the best case they play a key role for the quality of the results.

The country information collected from the industrialized countries is heterogeneous and has gaps in what has been identified as "essential information". The majority of countries do not have sampling based national forest inventories. In these cases national information is usually based on an aggregate of stand-wise inventories for management planning, which are incomplete in coverage. The aggregates have unknown precision, and experience shows that they normally underestimate growing stock and growth.

Tropical countries: FAO is presently finalizing its forest resources assessment 1990 for the tropical countries. The questionnaire approach that has been used in pre 1980 assessments has been rejected in view of the weak basis of country information. Instead the assessment is using a combination of two approaches to the collection of data.

One approach is based on a systematic review of existing information available in the countries. This information has been compiled from available documents in the FAO library and in countries and stored in the Forest Resources Information System (FORIS). After thorough analysis and consistency checking an interesting process has taken place to make the maximum of what had been brought together. Existing multi-date observations of forest cover have been used to derive a model that describes forest cover as a function of population data and eco-floristic zone. This model has been applied (1) to bring all multi-date and single-date information to the base years 1980 and 1990 and (2) to fill gaps. A total of about 150 multi-date and 1000 single-date observations, each referring to a sub-national unit, have been used.

The other approach uses high resolution satellite data from a stratified random sample of locations to derive state and change of forest cover area. For each location two images from close to 1980 and close to 1990 have been retrieved. These images are being overlaid. The common cloud-free area is covered with a raster grid and for each dot in the grid the land/forest class at both points in time recorded. 9 land/forest classes are being distinguished. The approach produces two types of results: (1) an independent estimate of state and change of forest area and (2) a "change matrix" showing the pattern of changes. The latter is genuinely new information on the regional scale. It will increase our understanding of the deforestation process and even help us to get some quantitative information on forest degradation.

The methods and in particular their combination have been reviewed by the scientific community and recently by an in-depth review team and found sound.

Approaches for the Future

Industrialized countries: It is not within my mandate to deal with this issue. Therefore, I may only mention that a Boreal Forest Research Association has been created and will hold its first formal meeting in September this year in Alaska. Two fields of activity for this association have so far been identified, one of them being assessment and monitoring. There is a possibility that new approaches will be discussed under this activity, e.g. the use of satellite remote sensing for getting an independent estimate of state and change in some major forest variables. Such an undertaking would produce an interesting complement to the questionnaire approach which is currently in use and has the above-mentioned limitations

Tropical countries: The Forest Resources Assessment 1990 project of FAO (FRA90) comes to an end this year. The programme of FAO in the field of both national and global assessments will go on. As already mentioned the preparations for continued global activities have begun. This symposium gives a welcome opportunity to expose our ideas to an audience of experts coming from research and from practical application. Let me use this opportunity and explain what we have in mind.

The team which made an in-depth review of FRA90 in April this year recommended that both approaches used, i.e. collect and organize existing reliable information and produce an independent estimate based on a sample of satellite scenes, should be used even in the continuation. It also recommended that environmental aspects be given increased attention. Moreover the team made one recommendation which is particularly interesting in the context national inventories serving global monitoring. A shift in emphasis was recommended towards country capacity building. This should serve two purposes:

(1) Strengthen the capability of countries to carry out national assessments and to integrate them in the processes of planning, evaluating effects and rectifying inadequacies
(2) Improve the quantity and quality of country information that can be used for global assessments.

In the aftermath of the review the idea is taking form that the Forest Resources Information System (FORIS) could be used as a tool in a programme of country capacity building. FORIS contains the original data which FAO has collected from countries, all put in a common format. In workshops this data base can be presented and made available. This provides an opportunity to discuss the role of forest resources information in the processes of planning, evaluating effects and rectifying inadequacies. It will be stressed at such occasions that information needs on the national level will go far beyond the core information that has been compiled for global uses. As the review team pointed out FORIS is simple and user-friendly. It lends itself to build on at national level as found suitable at that level. With the format of the core information unchanged FORIS can help harmonizing national information provided for global and regional studies. Moreover FORIS can become a useful means of communication. It may help establishing a net of country correspondents similar to that of the industrialized countries.

These ideas are still quite new. If they stand critical review FAO may try to find sponsors to finance a country capacity building programme along these lines. In the best case we will really see national inventories serving global monitoring.

REMOTE SENSING AND WORLD FOREST MONITORING

Leo Sayn-Wittgenstein
Director General
Canada Centre for Remote Sensing
Department of Energy, Mines and Resources
Ottawa, Ontario, Canada

ABSTRACT

In recent years the emphasis in world forest monitoring has moved strongly towards environmental objectives. This has increased the potential role of remote sensing, because two areas in which remote sensing excels, namely the provision of synoptic information and the observation of dynamic events are now the top priorities. In comparison to other monitoring activities, forest monitoring has the great advantage that it can build on past experience in forest classification and forest inventory projects.

Current trends in technology indicate that remote sensing will play a larger role in world forest monitoring. Important, recent advances include an increasing number of useful earth observing satellites, the advent of radar satellites, the use of meteorological satellites for regional monitoring, and major improvements in our ability to manage the vast quantities of data that will be available.

Keywords: remote sensing, forest monitoring, environment, earth observation

INTRODUCTION

Among the many recent changes in the world forest monitoring, none has been more important than the shift in the main objectives of monitoring, away from the traditional problems of forest inventory and timber supply, towards environmental concerns. Remote sensing has been in the forefront of these changes, in part because of the growing capabilities of Earth Observation satellites, but also because the new environmental priorities present demands in areas where remote sensing is at its best, and place less emphasis on detailed forest inventory information, which is largely unattainable by satellite.

The basic definition of world forest monitoring remains unchanged as the systematic observation of the world's forests. However, the new priorities involve remote sensing to an increasing degree in the observation of land use patterns and changes in forest cover, in forest damage assessment and the observation of dynamic events, including seasonal changes. The technical prerequisites remain as the establishment of a baseline describing current conditions, followed by periodic observations to determine changes from this baseline.

THE ADVANTAGES OF REMOTE SENSING

Remote sensing, the science of using aircraft and satellites to observe the surface of the Earth and its environment, is a mature technology which has convincingly demonstrated the many ways in which it can contribute to the survey of Earth's resources. One of its most important contributions to global monitoring is forest monitoring, because forests and open woodlands cover so much of the Earth's surface, especially in the more productive and populated regions of the world. Also, forests and woodlands appear prominently on satellite imagery and have to be understood and observed, even if one's primary interest is not forestry, but some other discipline, such as geology, wildlife, or the study of soil, water, and the atmosphere. Forestry information provided by satellites includes the presence or absence of forest cover, the approximate tree species composition and indications of stress or damage from insects, diseases, drought, or pollution. Erosion, deforestation and the destruction of forests by fire show up particularly well. Remote sensing satellites not only provide the most important data required for world forest monitoring, but they do so at frequent, regular intervals, exactly as required by any monitoring system. In addition, radar satellites have overcome the problem of cloud cover, which until recently was an important obstacle to global monitoring.

The resolution of data from the current, major Earth observation satellites is largely in the range of 10 to 50m. (Thirty metres for the optical sensors of the Landsat Thematic Mapper and 10m for the panchromatic band of SPOT). Optical satellites are complemented by meterological satellites that provide observations at resolutions in the vicinity of one kilometre and by radar satellites that are unimpeded by darkness and rain; both will be discussed in more detail below.

Resolutions of 10 or 30m mean that a large tree, or a group of trees, that is in contrast with its surroundings can be observed. Since satellites orbit the earth at regular intervals, the same location can be observed again, and again. Today, the state of the art in remote sensing is such that the error in the position of successive observations is usually less than one resolution element; this means that a large tree, or group of trees, can be tracked for many years. This ability meets all the classical requirements of monitoring: the initial data are used to establish a baseline, which is then systematically observed using standardized methods that remain unchanged for many years, over the life of a satellite, or series of satellites.

As all statisticians know, reliable, successive and correlated observations often mean that one can estimate changes with a precision that is higher than that of the original baseline.

All this is familiar to foresters who know the advantages of permanent sample plots to estimate changes and to maintain a forest inventory. There is, however, a major difference from traditional surveys: we are no longer dealing with a relatively small sample of permanent sample plots, but we can now follow millions of individual 10m x 10m or 30m x 30m picture elements (pixels) which are used to compile global and regional information. Ground sampling will still provide calibration data and supplementary information, but the core data set will be the approximate equivalent of a 100% survey, as each and every pixel of forest land is observed. The amount of information that can be extracted from a pixel will continue to increase as technology advances, and technical and research priorities will shift from sampling procedures and interpretation to the management of unprecedented quantities of data. The challenge will be to extract useful information from a mass of data and this in turn requires a precise definition of the objectives of monitoring.

THE ORIGINS AND OBJECTIVES OF WORLD FOREST MONITORING

The origins of global forest monitoring lie in at least three different sources that each contribute different approaches and objectives. The three areas that can claim close links to the development of world forest monitoring are:

- Forest reconnaissance and classification
- Forest inventory
- Environmental interests.

All three have made major contributions to world forest monitoring and any effective monitoring system must involve a combination of their objectives, philosophies and techniques.

Forest Reconnaissance, Classification and World Forest Monitoring

It is easy to see the similarities between the global view from satellites and the observations of early explorers and of scientists who accompanied them. The similarity is so great that the world's space agencies have designated the year 1992, the 500th anniversary of Columbus' arrival in the New World, as the International Space Year with the Theme of "Mission to Planet Earth" with all that this implies about new discoveries and understanding of the Earth and its environment. Forest monitoring by satellite is part of this endeavour and it, too, has much in common with the early discoveries and reconnaissance surveys which preceded colonization and industrial development.

One major contributor to global forest monitoring is the wealth of information and experience contained in the many systems of forest classification that have been developed during scientific exploration of the forest. Forest classification has much in common with discovery because its goal, too, is to understand the forest. The general approach is to try to describe a range of complex and varied forest conditions in a way that allows the division of the forest into relatively uniform parts, each identified by its essential characteristics.

The number of classification systems is large and the individual systems often have little in common with each other. Differences may, for example, be due to divergent objectives: a forest inventory classification describes a forest in terms of tree size, species composition and timber volume, while an ecological classification may rely on floristic descriptions and the stage of plant succession. Biophysical classifications combine characteristics of vegetation, landform and drainage, while other systems classify on the basis of climate, elevation, soil, drainage, and so on..

Each system tends to be a book in itself, with its own advantages, methods and following. Canada, for example, has many co-existing and often incompatible classification systems. A summary of Canadian systems recently appeared in a special issue of the Forestry Chronicles. In view of the fact that the present Symposium is held in honour of Professor Ilvessalo, it is worth noting that the prologue to this issue begins with the sentence: "Forestry in Canada has a 65-year tradition of site classification whose beginning in the late 1920s is associated with the visit to North America of Ilvessalo, a student of Cajander, the Finnish ecologist." (Rowe, 1992).

The Scandinavian countries have done more than anyone else to advance common, national standards in forest classification. Elsewhere, however, there is little standardization and often little room for compromise between systems. Even apparently simple matters such as the definition of "forest land" pose large difficulties, especially in surveys that cross several jurisdictions or cover the transition from forest to tundra, grasslands, and agriculture. This is an unfortunate weakness which the forest community has to correct. A widely accepted system of forest classification could provide a common language for global forest monitoring from space. In the absence of substantial agreement on a forest classification, remote sensing projects tend to develop their own classifications, based largely on what is technically feasible in interpreting satellite data. As a result, global forest monitoring systems may forge ahead without the advantage of the accumulated knowledge in forest classification.

Forest Inventory and World Forest Monitoring

The second group with a major influence on world forest monitoring is the forest inventory community. It is natural for foresters to regard global forest monitoring as an extension of local or national forest inventories. After all, forest inventories contain most of the information that is of interest in global forest monitoring. For example, most world forest cover maps have been compiled from forest inventory summaries. However, forest inventories differ so much in standards, schedule and coverage that it is virtually impossible to sum up the component parts while maintaining reasonable accuracy and timeliness.

The weaknesses of the traditional cartographic approach to global land cover mapping has been demonstrated by Townshend *et al.* (1991) who compared global land cover statistics from sixteen difference sources and found large inconsistencies between estimates separated by only a few years. "Forest", "woodland and shrubland", "savanna", and "grassland" were among the classes considered in this study.

The most ambitious global forest inventory is the world forest inventory or "Forest Assessment 1990" of the Food and Agriculture Organization of the United Nations. This project relies on satellite data and a multistage sampling design. Its main objective is to complete a re-inventory of the global and national forest resources with emphasis on an overview of the forest resources available for economic development and sustained-yield management. Conceptually "Forest Assessment 1990" is part of the global monitoring networks of the United Nations Environmental Program (Gwynne, 1989). A recent summary of the project is given by Kalensky, Reichert and Singh (1991) and the methods of applying remote sensing are discussed by Singh and Poso (1989).

Apart from this global effort, remote sensing has played a relatively small part in national, regional and local forest inventories. This is partly due to the human resistance to change found in any field where there already is a proven and well established way of doing things. It is also due to the fact that forest inventories require detailed information on tree species, stand height, age and growth rates, that cannot be obtained by satellite. As a result the main contribution of satellites to traditional forest inventories has been in map updating, in showing the location of new roads and of recently burned and harvested areas.

Professionals in forestry and in agriculture tend to rely on statistics when completing surveys of large areas. Small sample plots are carefully selected, usually with known probabilities, and detailed measurements are made and aggregated to produce the final results. Foresters, almost by tradition, had little use for satellite images showing broad general patterns in their forests; the tradition is to start with local detail and then, maybe, to work up to regional or national summaries. In traditional forestry, synoptic views seemed appropriate for geographic descriptions and research, but not for operational use. This is in contrast to the new breed of environmental scientists who begin a forest survey with a view from space obtained by satellite.

Environmental Interests

The third and today no doubt the most important source of demands for global forest monitoring is the need for environmental information. The recent decades have seen a growing and well-founded concern for the state of Earth's environment. Both scientists and the general public are well aware of the importance of protecting the environment. Information that was previously collected at only local or national levels must today be produced at a global scale. The environment is everybody's business.

In the Global Village of the year 2000 we will all be watching each other's back yards, and governments will be obliged to take strong positions on the environment and to produce environmental information for their own use, for their citizens and for the international community. Failure to do so will have serious political and social consequences. All governments are under increasing pressure to demonstrate that their management practices are in good order and do not threaten the global environment through, for example, deforestation, pollution, land degradation, and destruction of wildlife habitat.

This means growing demands for up-to-date information on the extent and condition of our forests, on the degree of human activity, and on damage and stress from whatever cause. All this information is required in a form that is readily understood by the general public and by officials who are not necessarily experts in forest inventory. Quantitative remote sensing data as well as synoptic views and graphic pictures from space will be invaluable, because a picture is always worth a thousand words. Remote sensing from satellites is outstanding in providing precisely the type of information that is required.

TRENDS AND RECENT DEVELOPMENTS

Today the emphasis in world forest monitoring is on reliable, timely information. Prompt advice is more important than high levels of precision. Another critical requirement is the ability to convert the mass of available satellite data into useful information and to present the results in a way that is readily interpreted and understood.

The world's remote sensing and space agencies are well aware of these environmental imperatives and many recent developments have made a direct contribution to global environmental and forest monitoring. For example:

The number of satellites and the amount of available data will greatly increase. Remote sensing from satellites began in 1972 with the launch of the first Landsat and for many years using satellites for forest mapping meant using Landsat. In 1986 Landsat was joined by SPOT 1, the first in a continuing series of SPOT satellites. In addition, we now have the following satellites that are of value in forest monitoring:

- The continuing series of NOAA satellites,
- ERS-1, the European Space Agency's radar satellite, launched in 1991 (C-band, resolution 30m),
- J-ERS-1, the Japanese radar satellite (L-band, resolution 18 m), launched in 1992,
- Almaz 1 (actually the second Almaz), a Russian radar satellite (S-band, resolution 20–45m), launched in 1991,
- the Japanese Marine Observation Satellite (launched in 1990) whose optical sensors could, in the event of a Landsat failure, be considered a possible alternative,
- The Indian Remote Sensing Satellites, launched in 1991 and 1992, primarily for land resource observation,
- Russian (Priroda) satellites collecting space photography (hard copy recovery, nominal resolution 5m). Most recent launch, May 1992 (Resource F2 satellite).

Some of the above are experimental, but obviously the choice for the users of satellites has greatly expanded. This trend will continue and will accelerate with the launch of the fully operational Canadian Radarsat (early 1995, C-band, resolution 10–100m) and with new satellites currently proposed by the world's space agencies. A comprehensive list of current and proposed Earth observing satellites has just been issued by the British National Space Centre, on behalf of the international Committee on Earth Observation Satellites (CEOS, 1992).

The price of satellite data has greatly increased in recent years, but it is also entirely possible that the late 1990's will see a more competitive situation and that global monitoring programs will benefit from recent policies that provide data required for environmental purposes at substantially lower cost.

Radar satellites will provide reliable information on cloud-covered areas. One of the most important recent developments for global forest monitoring is the advent of radar satellites which have the ability to monitor forests in darkness and through clouds. This is of enormous importance for tropical forests, because optical satellites often cannot provide reliable coverage of tropical areas because of persistent cloud cover. For example, there still are areas in West Africa, in the Amazon basin and in Southeast Asia that have never been satisfactorily mapped by SPOT or Landsat; radar will provide the required coverage.

Current radar satellites include the European Space Agency's ERS-l satellite, the Russian Almaz, and the Japanese J-ERS-l satellite, which at the time of writing had successfully deployed its SAR antenna in April of this year. These largely experimental satellites will, by early 1995 be joined by the Canada's Radarsat, a fully operational satellite, specifically designed for application in natural resource mapping and monitoring. One can expect that in the late 1990's radar will be the dominant sensor for Earth observation. In addition to providing information on cloud-covered areas, radar satellites will contribute to world forest monitoring in two main areas:

- The mapping and observation of land forms, topography and terrain, including the monitoring of soil moisture, water levels and soil erosion.
- The mapping of forest cover including the delineation of the forest/non-forest boundary and the identification of major forest types. Synthetic aperture radar images show major structural change in forest cover such as those resulting from the clearing of land, harvesting operations, road construction and major forest damage. Optical sensors provide additional information on vegetation conditions. The best strategy is to combine data from optical and radar satellites to obtain the best possible information for forest monitoring.

Foresters still have a great deal to learn about the interpretation of radar imagery, especially in the tropics. In April/May 1992 the Canada Centre for Remote Sensing, in cooperation and with support from the European Space Agency and other organizations, took its Convair 580 radar research aircraft to South and Central America to carry out experiments to prove the value of radar in the tropics. Following recent major upgrades, the radar system on the Convair is the most advanced civilian airborne SAR facility in existence. It is a system that has already proved its value in northern forests (Figure 1). It offers fully phase-coherent C and X band synthetic aperture radar with polarimetric and interferometric modes. The results of this experiment, which is known as SAREX-92, are now under analysis, but preliminary returns fully confirm the potential of radar for mapping and monitoring tropical forests.

Meteorological satellites will play an increasing role in world forest monitoring. In addition to Earth observation satellites such as SPOT, Landsat and the new radar satellites, world forest monitoring will rely on the use of meteorological satellites for global and regional observations. Data from these satellites are of lower resolution; for example, NOAA AVHRR (Advanced Very High Resolution Radiometer) data, which have found the greatest application, have a maximum resolution of 1.1 km. However, these satellites provide global coverage every one or two days. Their value in monitoring has been clearly demonstrated in mapping deforestation in Amazonia (Malingreau and Tucker, 1988), in the work of the EROS Data Center of the United States Geological Survey (Eidenshink, 1992), and in the Canadian Crop Information System and related developments (Cihlar *et al.*, 1990), (Brown and Graham, 1990). The information obtained can also be used to map land cover classes, seasonal changes and the effects of drought on vegetation. Last year the EROS Data Center and the Canada Centre for Remote Sensing cooperated in producing a North American vegetation index map which can be seen on the cover of the June 1992 issue of Photogrammetric Engineering and Remote Sensing.

A recently developed system, known as GEOCOMP, will make these methods even more attractive. GEOCOMP, completed in 1992 under contract to the Canada Centre for Remote Sensing, produces AVHRR data composites that are radiometrically corrected, geocoded and brought to any desirable standard map projection. GEOCOMP is an excellent tool for frequent and relatively inexpensive forest monitoring at regional and national levels. Annual maps can be readily produced to show major land cover changes, and more frequent coverage is possible, if required. For example, given the usual limitations due to cloud cover in temperate regions, it is possible to produce maps at 7 or 10 day intervals to monitor phenological changes in the forest. Additional, supporting information can be obtained from SPOT and Landsat, which carry high resolution sensors.

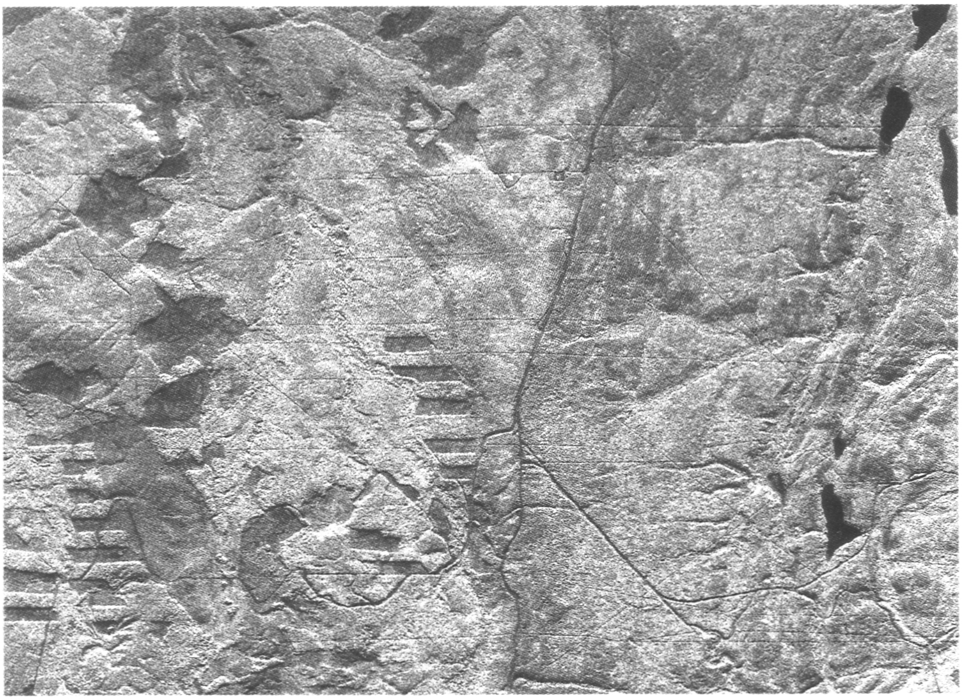


Figure 1. This area of boreal forest north of Whitecourt, Alberta was imaged with the CCRS C-band SAR on June 28, 1988. Areas of mature spruce (white and black) show the brightest returns, while lodgepole pine stands are noticably darker. Roads, drainage networks, clearcut areas, and a regenerating burned area are visible. (Pixel spacing 4.275m, resolution 7m, image reproduced at a scale of 1:75,000)

New technology will make it easier to extract useful information from available data. The satellites of future world forest monitoring projects will yield unprecedented quantities of data. For example, in the late 1990's the satellites of the United States Earth Observing System (EOS) are expected to produce data at the rate of approximately one terabyte per day. One terabyte is one million megabytes; all the books in the Library of Congress are estimated to contain three terabytes of data. Clearly, this rate will put enormous stresses on the systems for the reception, archiving, and distribution of data.

New technology, however, is rapidly increasing the efficiency of data management. For example, the rate of progress in data storage and retrieval is illustrated by a recent development at the Canada Centre for Remote Sensing. CCRS has maintained digital satellite data archives since 1972, and currently spends close to one million dollars per year on the maintenance of archives. A few years ago, in an attempt to reduce this cost, CCRS supported the development of an optical tape recorder proposed by a Canadian company, CREO Electronics Corporation. Today, several CREO tape recorders are installed at CCRS and are undergoing operational trials. Their specifications represent a major step forward: the capacity of each tape (35 mm wide, 880 m long) is one terabyte, equal to the capacity of 5000 Computer Compatible Tapes, or of 100 High Density Tapes. The average data access time is 28 seconds, the maximum 60 seconds. The archive life of each tape is estimated at 20 years. In summary, this new recorder represents a major advance in the efficiency of data management.

In general, anyone involved in the use of remote sensing for world forest monitoring will take advantage of trends towards the availability of greater computing power at sharply lower cost. Workstations with the power of a minicomputer and supported by advanced image interpretation and geographic information systems (GIS) are a reality. The link between remote sensing and GIS systems may well emerge as the most significant development: remote sensing provides vital input to GIS systems, and the digital, geographically referenced data obtained from satellites are easy to use. This provides unprecedented power for the analysis of satellite data in conjunction with other geographically referenced information.

In addition, the new GIS and image interpretation systems are increasingly user-friendly, and their operation requires little understanding of the complexities of computer programming and operating systems. A typical forest monitoring workstation will have access to a network of other users and data banks, including multidisciplinary scientific data sets, to forest inventory data bases (maintained by forestry organizations) and to national and international satellite data catalogues, maintained by space agencies and satellite operators. Workstations of this kind are already in place in several organizations.

Indeed, early next year any interested individual with access to an IBM-AT or compatible computer will be able to scan a large collection of satellite data, and to carry out his or her own exploration of the global environment. This will be the result of the Global Change Encyclopedia also known as "GEOSCOPE", an international, educational project completed in Canada as part of the International Space Year (Simard, 1992). GEOSCOPE is a collection of global data sets, including satellite data for 40 difference parameters, ready for display or analysis. Among its many themes are global vegetation cover, seasonal changes in rainfall and vegetation, deforestation, forest fires and insect damage. In late 1992 GEOSCOPE will be available for public distribution as diskette or CD ROM. It will be kept up to date and expanded and will probably play a significant role in increasing public awareness of global forest monitoring.

REFERENCES

Brown, R.J., William, G.B., Graham, K.W., 1990: Satellites monitor global vegetation condition. GEOS, vol. 19, no. 2, pp. 12–16.

CEOS (Committee on Earth Observation Satellites), 1992: The relevance of satellite missions to the study of the global environment. Report prepared by British National Space Centre for United Nations Conference on Environment and Development, Rio de Janeiro.

Cihlar, J., Ahern, F.J., D'Iorio, M.A., Guindon, B., Teillet, P.M., Fisher, T., 1990:

Mapping land cover of Canada from AVHRR data. International Geoscience and Remote Sensing Symposium, IGARSS '90. Washington, D.C. Proceedings, vol. 2, pp. 1237–1243.

Eidenshink, Jeffrey C., 1992: The 1990 Conterminous U.S. AVHRR data set. Photogrammetric Engineering and Remote Sensing, vol. 58, no. 6, pp. 809–813.

Gwynne, M.D., 1989: Global monitoring, data management and assessment within

GEMS and GRID. International Conference and Workshop on Global Natural Resource Monitoring and Assessment. Venice, Sept. 2430, 1989. Proceedings, vol. 1, pp. 87–97.

Kalensky, Z.D., Reichert, P.G. and Singh, K.D., 1991: Forest mapping and monitoring in developing countries based on remote sensing. Fernerkundung in der Forstwirtschaft (Wichmann/Karlsruhe), pp. 230–257.

Malingreau, J–P. and Tucker, C.M., 1988: Large-scale deforestation in the southeastern Amazon basin of Brazil. AMBIO, vol. 17, pp. 49–55.

Rowe, J. Stan, 1992: Prologue (to special issue of Forestry Chronical on site classification). Forestry Chronicle, vol. 68, no. 1, pp. 22–24.

Simard, Rejean, 1992: GEOSCOPE, an interactive Global Change Encyclopedia.

Proceedings EURISY (European International Space Year) Conference, Munich, March 30 – April 3, 1992.

Singh, K.D., and Poso, S., 1989: Methodological requirements for global forest inventory and monitoring. International Conference and Workshop on Global Natural Resource Monitoring and Assessment. Venice, Sept. 24–30, 1989. Proceedings, vol. 2, pp. 609–617.

Townshend, J.R.G., Justice, C.O., Li, W., Guerney, C. and McManus, J., 1991: Cover classification by remote sensing: present capabilities and future possibilities. Remote Sensing of Environment, vol 35, pp. 243–256.

THE RESULTS OF THE UN-ECE/FAO 1990 FOREST RESOURCE ASSESSMENT
(Temperate-zone)

T. J. Peck & A. V. Korotkov
ECE/FAO Agriculture and Timber Division
Geneva

ABSTRACT

The UN-ECE/FAO Forest Resource Assessment (temperate-zone) 1990 has been carried out in accordance with the programme of work of the Joint FAO/ECE Working Party on Forest Economics and Statistics, a subsidiary body of the FAO European Forestry Commission and the UN-ECE Timber Committee, as part of the Global Forest Resource Assessment.

The geographic coverage of the Assessment includes member countries of the ECE region (Europe, the former USSR and North America) as well as three other developed temperate-zone countries (Australia, Japan and New Zealand).

The publication of the survey is entirely based on national replies to the detailed enquiry and consists of two volumes :

Volume I	–	General forest resource information, and
Volume II	–	Benefits and functions of the forest

The Assessment contains valuable information covering approximately one half of the world's total forest resource and gives a good basis for the careful analysis by forest policy makers, scientists, forest managers, ecologists and others concerned with the forest resource.

The principal results of the assessment were issued in advance of the main publication in June 1992, under the title *Main findings of the UN-ECE/FAO Forest Resource Assessment* 1/.

One of the main findings that is common to most of the temperate-zone countries is the continuing expansion of the temperate-zone forest resource. The Assessment has also revealed the increasing relative and absolute importance of the non-wood functions of the forest in the region.

The results of the Assessment raise some aspects to be investigated further and problems to be solved for reaching a harmonious balance in the utilisation of forest resources according to economically and ecologically sound sustainable forest management principles

The experience gained in the process of the preparation and implementation of the 1990 Assessment will help to improve future Forest Resource Assessments.

INTRODUCTION

The present Assessment of the Temperate-zone Forest Resources is the latest in the series of international assessments that have been carried out in collaboration with FAO since the middle of the century, at approximately 10-year intervals.

The previous assessment, covering the major part of the temperate-zone regions and relating to the period around 1980, was published in 1985 as The Forest Resources of the ECE Region (Europe, the USSR, North America).

Growing professional and public interest for such Assessments may be explained by the

---

1/ UN-ECE/FAO, ECE/TIM/60

growing importance of forests and their role in the present-day world. The extremely positive attitude to these projects of Governments at sessions of the ECE Timber Committee and the FAO European Forestry Commission and of national experts at meetings of their subsidiary bodies have proved this.

Origin and Development of the Project

It is a real pleasure to recall that preparations for the 1990 Global Assessment were initiated here in Finland (at Kotka in October 1987) at the *ad hoc* Meeting of Experts on Global Froest Resource Assessment, organized jointly by FAO, UN-ECE and FINNIDA.

The implementation of the temperate-zone part of the project has been undertaken in accordance with the programme of work of the Joint FAO/ECE Working Party on Forest Economics and Statistics.

This subsidiary body of the FAO European Forestry Commission and the UN-ECE Timber Committee has supervised this survey through all the stages of its implementation.

Methodological Approach

From the outset it was agreed to implement the temperate-zone part of the Assessment by means of a detailed enquiry, covering the most important inventory information.

Taking into account the recommendations of the Kotka meeting, the "Common Framework for the World Forest Resource Assessment 1990" has been elaborated by the FAO Forestry Department in conjunction with the Joint ECE/FAO Agriculture and Timber Division, and approved by the second *ad hoc* meeting of experts in Venice, Italy, in September 1989.

The objective of this methodological paper was to provide *a common basis* for the Global Assessment which would be carried out in many tropical and temperate-zone countries with diversified types of forest and categories of forest inventory information. Another major aim was to maintain comparability with earlier assessments to the extent possible.

This document served as a good basis for the elaboration of the enquiry for the temperate-zone part of the Assessment but failed to provide *a real common basis* for the Global Assessment. The main reason for this is that the definitions and classifications used in national inventories differ widely even within the temperate-zone region and, in practice, some tropical or temperate-zone categories could not be "translated" into a real "common framework".

Table 1. Stages of the ECE/FAO 1990 Forest Resource Assessment (temperate-zone)

1. Publication of "Forest Resources of the ECE Region (Europe, the USSR, North America)", 1985
2. FAO/ECE/FINNIDA ad hoc meeting of experts, Kotka, Finland, October 1987
3. The second FAO/ECE ad hoc meeting of experts, Venice, Italy, September 1989
4. The 17th session of the Joint FAO/ECE Working Party on Forest Economics and Statistics, Geneva, December 1989
5. Distribution of the enquiry to the countries, March 1990
6. Countries' replies to the enquiry, 1990–1991
7. Preliminary results of the assessment, July-August 1991
8. Third FAO/ECE ad hoc meeting of experts, Geneva, August 1991
9. The 18th session of the Joint Working Party, August 1991
10. Publication of "The Forest Resources of the Temperate Zones : Main findings of the UN-ECE/FAO 1990 Forest Resource Assessment", June 1992
11. Publication of "The Forest Resources of the Temperate Zones (2 volumes), late 1992

The enquiry for the temperate-zone part of the Assessment, including terms, definitions and the questionnaire, was approved by the 17th session of the Joint Working Party in December 1989 and circulated to countries in spring 1990 (Table 1).

The geographic coverage of the 1990 Assessment includes the member countries of the ECE region (Europe, the former USSR and North America) as well as three other industrialized temperate-zone countries (Australia, Japan and New Zealand). (Figure 1)

Table 2. The contents of the enquiry are shown on the transparency

Contents of the enquiry (table 2)

FRA(TZ) –90

1. General notes on the enquiry, including terms and definitions;
2. Part I: General Inventory Information
3. Part II: The Role of Forests in Supplying Environmental and Other Non-wood Goods and Services (Non-wood Benefits).

To give an impression of the scope and range of basic forest resource information (data) used in the present Assessment, a list of the tables which were offered to national correspondents in the enquiry and which formed the basis of the survey is shown in Table 3.

Table 3. Basic forest resource information included in Volume I of the Assessment

FRA(TZ)-90

Tables of the enquiry	
1	Overall land classification
2	Forest and other wooded land by type and species groups
2A (supplement.)	Trees outside the forest
3	Forest and other wooded land by main categories
4	Forest and other wooded land by ownership and management status
4A (supplement.)	Public land administered by the Forest Authority
5	Structure of holdings of forest and other wooded land
6	Distribution of exploitable forest by age-classes
7	Changes in area of forest and other wooded land
7A (supplement.)	Reforestation (artificial and natural) 1980 to 1990
8	Total standing volume of forest and tree resources
8A (supplement.)	Growing stock (GS) on forest and other wooded land
9	Estimates of standing volume and mass of above-ground tree biomass
9A (supplement.)	Estimates of total volume and mass of tree biomass
10	Annual increment on forest and tree resources
11	Fellings

Practically all the information provided by the national correspondents has been used in the publication in compliance with the secretariat's principle that if national correspondents take the trouble to collect and provide it, it should be published.

National Inventories as a Basis for the Assessment

One of the essential arrangements for the collection of information has been the close and effective links between the FAO/ECE secretariat and the national correspondents nominated by countries.

They were responsible for filling in the enquiry and the secretariat has maintained contacts with them on any queries which have arisen in connection with the replies.

Close analysis of the national replies has shown that the most complete and reliable replies to the enquiry were received from countries with a well-developed forest inventory system.

At the same time, difficulties in reconciling national classifications and definitions with the accepted terms and definitions for this particular Assessment made it impossible for some national correspondents to provide all of the more important figures. In turn, the lack of data for some countries created the problem of making regional totals, and the secretariat was obliged, in some cases, to make its own estimates of regional totals in the general tables.

The following are just a few quotations from the correspondents' replies to the enquiry which illustrate the problems of reconciling national data within the international Assessment :

Austria "All figures are revised" on the basis of "the latest Austrian Forest Inventory's interpretation which was published in September 1991. Some data have to be estimates as Austria has not surveyed these figures".

Belgium "for the time being has no reliable means of evaluating exactly how the different patterns of land use are evolving relative to one another". "No data are available to complete this table". (Tables on "changes in area" and "reforestation").

Bulgaria "Exploitable forests are not treated separately, but the data for forests as a whole almost correspond to figures in this category". (Tables on "fellings and removals").

CSFR "More precise data on the size and structure of private forest holdings are not available."

Denmark "Difficulties were encountered partly because Danish forest statistics are based on definitions different from those of FAO and partly because up-to-date figures are missing – the latest official statistics are from 1976 – and finally because the material had to be derived from many sources."

Finland "The National Forest Inventory in Finland is designed to cover a portion of the country every summer and hence the entire country over a period of 10 years."

Incidentally, it should be mentioned in parentheses that Finland provided one of the most complete and consistent replies to our enquiry.

France "Inventories are carried out by the national forest inventory service, which has for a very long time been taking rigorous measurements of the forest area in France for which the economic function is dominant ... formations whose primary function is not economic are not covered by any on-ground studies. Therefore data are not available on standing volume, wood production, distribution by ownership status, etc. ... for this area."

Italy Reply to one more request to complete some of the most essential tables in the enquiry: "All efforts have been made by national experts to provide the latest and most reliable information. No additional data are currently available ...."

Sweden "The information available on changes in area of forest and other wooded land during the 1980s is very unreliable. The net changes, however, are quite small."

United Kingdom "All forests are exploitable. There are no legal bars to felling and no areas where felling is ruled out for technical or economic reasons. Virtually all forests are multi-purpose. No measurement is available of separate purposes."

Yugoslavia "Data refer to the 1979 census of forest resources. According to the estimate of the correspondent it should be 4 per cent higher by the end of 1987."

The former USSR "The annual increment of tree resources has been determined from the results of the State forest inventory of 1988 for all forests, including collective-farm forests. There are no data available concerning natural losses."

Canada "The 1990 estimates are based on three provinces only."

USA "The US Forest Service definitions of timberland most closely approximates the FAO definition of exploitable forest land ... The Forest Service breaks down forest land into only two classes : timberland and reserved forest land."

Japan "Net change in area" for 10 years is estimated from net change 1981 to 1986 (5 years). Calculation was attached.

These quotations should not be taken as criticisms or complaints. On the contrary, the secretariat is very grateful to all the correspondents of the countries involved who expended a considerable amount of time and effort in completing the enquiry. It was by no means an easy task.

The above quotations illustrate the problems of adapting national inventories for use in international assessments. Despite these difficulties, we have been able to construct a valuable database, even though parts of it have had to be complied on the basis of certain assumptions.

The results of the present assessment have confirmed once again that the success of an international Forest Assessment is closely linked to and depends on the quality of National Forest Inventories.

Structure and Content of the Present International Survey

The preliminary results of the 1990 temperate-zone assessment were considered in August 1991 by the *ad hoc* meeting of experts and presented to the 18th session of the Joint FAO/ECE Working Party on Forest Economics and Statistics, which approved recommendations for finalizing the survey.

The principal results of the assessment, named Main findings of the UN-ECE/FAO 1990 Forest Resource Assessment, were issued in advance of the main publication in June of this year. A preliminary version of the Main Findings had been approved in April 1992 by a joint meeting of the ECE Timber Committee office-holders and the Executive Committee of the FAO European Forestry Commission.

Copies of this publication are available at the Symposium or can be ordered from the secretariat at Geneva.

The structure and content of the main 2-volume publication, work on which is virtually completed, are shown in Table 4 :

Table 4. Contents of the publication "The Forest Resource of the Temperate Zones"

The UN-ECE/FAO 1990, Forest Resource Assessment

Volume I – General Forest Resource Information
    – Introduction and explantary notes
    – Summary of results
    – Part I: Basic forest resource data (35 General Tables)
    – Part II: Country files

Volume II – Benefits and Functions of the Forest
    – Part I: Secretariat synthesis of countries' replies
    – Part II: Country by country presentation of the information received
    – Part III: Commentary prepared by the consultants

35 General Tables of Volume I, grouped in accordance with the categories of the information into 7 sections and supplemented by charts, schemes and graphics in order to give a more visual image of the forest resource structure, form Part I of the Volume.

Part II of Volume I contains additional information, tables of essential data and explanatory notes on a country by country basis.

The contents of Volume II and the structure of country files in Volume II are shown in Tables 4 and 5 respectively.

Table 5. Elements of country files in volume II

FRA(TZ) –90

Question A:	Importance of forest functions by area
Question B:	Production of forest products other than wood
Question C:	Policy and planning activities relating to forest functions
Question D:	Areas of public concern and conflicts between forest functions
Question E:	Reference material

As already mentioned, these two volumes include practically all the information received from countries. They can be considered as very interesting reference sources for policy-makers, managers and others concerned with forestry, ecology, wood consumption and nature conservation.

Among the UNCED Agenda 21 programme areas there is one of particular importance in connection with the topic being discussed here. This is the programme area aimed at "... strengthening capacities for the planning, assessment and systematic observation of forests and related programmes, projects and activities". In the process of implementing the project on the 1990 Assessment we have experienced serious shortages of resources, funds and capacity, which have no doubt affected the quality of the results.

The Results of the 1990 Assessment (Temperate-zone)

In a global context, forest and other wooded land of the temperate-zone regions (included in the present survey) accounts for 2.06 billion ha, which constitutes just over half of the world total. Forest and other wooded land constitutes the largest component of land use in terms of area in the temperate-zone regions – 39 %. Of the remaining area, 1.82 billion ha or 34% are estimated to be agricultural land and 27 % (1.45 billion ha) fall into other categories including built-on land, land used for infrastructure, desert, tundra and other types of land.

Figure 2 shows the distribution of forest and other wooded land among the temperate-zone regions. Out of the total, the former USSR's share is 46%, North America's 36 % and Europe's 9 %.

General Forest Resource Information

Basic forest resource information obtained in connexion with the present Assessment includes besides **land use classification** the presentation of forest and other wooded land according to: types, species groups, stocked and unstocked categories, ownership and management status, number and size of holdings, change in area over time, standing volume and growing stock, standing volume and mass of biomass, annual increment, fellings and removals.

Some of this information is presented in the following figures.

The share of forest and other wooded land varies considerably between regions, ranging from 68 % and 60 % in Japan and the Nordic countries respectively to less than 20 % in Oceania (Australia and New Zealand) and less than 9 % in northwestern Europe (Figure 3).

The data on **net annual increment** (NAI) is of particular value as it provides an indication of the productivity of the forest and also allows various analyses of forestry. Probably the most reliable increment figures are those for exploitable forest. The range of NAI per hectare on exploitable forest is very large and is dependent on such factors as site conditions, age-class structure and silvicultural regime (Figure 4).

The term **"exploitable"** is intended to convey the idea of forest (or other wooded land) that is not only in regular and sustainable use as a source of wood (whether managed or not) but which is also available and accessible for such use, even if not yet being so used.

Some countries outside Europe have problems with the concept of "exploitable" forest or other wooded land. This is one of the points to discuss in the light of future assessments. There are different proposals to change the term.

The share of exploitable forest in Europe is quite high – more than 89% of the total area of forest land or 133 million ha, while in the former USSR the share is much less (nearly 55 %) and in Canada less than 45 %.

The distribution of exploitable forest in Europe by sub-region is shown in Figure 5.

Ownership structure varies from country to country according to historical, social, political and other factors. (Figure 6).

Differences in site conditions, management regimes, age-class structures and other aspects give the different indices of the **volume of growing stock** per ha in different regions and countries.(Figure 7).

Species distribution can be better indicated by the growing stock data than by area, because of the difficulties of finding common definitions based on area of "coniferous forests" and "broadleaved forests". Of total growing stock of 112 billion m3 o.b. on exploitable forest in the temperate zones, 75.5 billion or almost exactly two thirds are coniferous and 36.5 billion of one third are broadleaved. (Figure 8).

Fellings on exploitable forest in comparison with net annual increment by sub-region are shown in Figure 9. The relationship between fellings and NAI gives a good indication of the evolution of the forest resources.

The wood harvesting intensity is shown on the following two transparencies :
(Figures 10 and 11).

Environmental and Other Non-wood Benefits and Functions

The objective of this part of the Assessment is to bring together as much quantitative and qualitative information as countries could provide on the importance they attach to the various functions of the forest, how these functions interact or conflict with each other and how their importance is changing over time.

Countries were asked to divide the area of forest and other wooded land on the basis of the level of importance – high, medium or low – accorded to each function. The functions to be rated were :

wood production
protection (of the environment)
water
grazing (or range)
hunting
nature conservation
recreation.

Figure 12 shows that (according to the aggregate of European countries' replies) after wood production and hunting, – recreation, protection and grazing have the next highest proportion of forest in the high importance category, although the last two as well as water have about three quarters of forests in the low importance category.

The replies of selected countries relating to wood production, hunting and recreation are shown in Figures 13, 14 and 15 respectively. They demonstrate clearly the different emphasis placed on the same function in different countries.

Generally speaking, the replies can be related to various conditions within the country, for example, extent of forest cover, population density, topography, standard of living and so on.

Other elements which were reflected in Volume II of the Assessment (besides the "Importance of forest functions by area") were shown in Table 5.

Main Findings of the Assessment

Summarizing the results of the 1990 Assessment (temperate-zone) it should be noted first of all that one of the main findings of the Assessment that is common to most countries in the temperate regions, so far as its significance for the long-term implications for policy is concerned, is the **continuing expansion of the temperate-zone forest resource.** Another, which emerges from the results presented in Volume II of the survey is the **increasing relative and absolute importance of the non-wood functions of the forest.**

Other findings of the Assessment may be presented as follows :

- 2.06 billion ha or about half of the world's total forest and other wooded land, are located in the temperate-zone regions, nearly one-quarter in the former USSR alone and nearly one-fifth in North America.
- forest cover (nearly 39% of land area) and forest per inhabitant (1.62 ha/cap) in these regions are as a whole appreciably above the world averages.
- between 1980 and 1990, forest area, growing stock and increment continued to increase in Europe and the former USSR, showing a continuation of the trend since 1950.
- fellings in the temperate-zone regions around 1990 totalled 1.86 billion m3 overbark (two-fifths in North America). In almost all countries in these regions, fellings have been rising steadily over the long-term but have remained below net annual increment, which explains the rise in growing stock.
- the environmental and other non-wood goods and services of the forest in the temperate-zone regions are of increasing importance to society, both in absolute terms and relative to wood production. The latter, however, remains the single most important function of the forest nearly everywhere.
- the majority of countries expect increasing emphasis in policy and planning to be given to the non-wood functions of the forest, in particular protection, water regulation and quality, nature conservation and recreation. The prevailing importance of wood production will be maintained, while the importance of hunting, grazing and specified non-wood products will also remain about the same as before.
- public attitudes towards the forest and forestry have been changing over the past decade, with increasing concern being expressed in many countries for the protection of the environment, conservation of forests, bio-diversity and meeting society's demands for non-wood benefits.
- conflicts do arise between different functions of the forest, most commonly between wood production and one of the other functions, notably environmental protection, hunting, nature conservation or recreation. Forest policies of a growing number of countries take this into account and methods are being improved for reconciling such conflicts.

It should also be noted that the main share in the area of the temperate-zone forests lies in the former USSR and North America, and forest policy in these regions has an important influence on the situation in temperate forests as a whole.

It could also be concluded from the Assessment that most countries expect that more policy and planning will be directed to specific non-wood functions of the forest and there is a need to find solutions to conflicts that sometimes arise between the different functions of the forest.

Considering carefully the database obtained in the course of the present Assessment one could conclude that further analysis will be necessary in order to determine what could be the most appropriate policy responses to this latest information on the temperate forest resource, especially since they might well differ from one country to another. It should be considered, for example, whether the continuing build-up of the temperate forest resource is beneficial or not to the countries concerned from both the economic and the ecological points of view. Will the net productivity (productive potential) of the forest resource, in terms of output capacity for the whole range of goods and services, tend to rise or to fall relative to gross potential as the tree part of the forest ecosystem moves towards an older age-class distribution? It could be argued that in some respects the ratio of net productivity to gross productivity would deteriorate, for example, a decline eventually to zero of net annual increment of wood in an overmature forest as a result of the increasing proneness of older trees to damage and decay of one sort or another. On the other hand, this same development could be seen as beneficial from such points of view as bio-diversity and nature conservation.

One point should also be mentioned separately : problems related to forest damage and threats to the forest ecosystems of the temperate-zones have not been subject to the present global forest resource assessment. These aspects continue to be monitored and analysed in specific UN-ECE and FAO working groups.

Plans for Future Forest Resource Assessments

The experience gained in the process of the preparation and implementation of the 1990 Assessment should serve future Assessments.

The **considerable pressure** from governments, policy makers, special interest groups, etc. for more accurate and relevant data on the forest resources throughout the world, as well as the need for these data to be more comparable acts as a **stimulus** on the activity of international organizations in this field.

The 1990 Forest Resource Assessment has triggered off some new and interesting projects as its follow-ups.

Proposals of the Joint FAO/ECE Working Party on Forest Economics and Statistics

The Joint FAO/ECE Working Party recommended at its 18th session in August 1991 that an *ad hoc* meeting to start the preparation for the next Global Forest Resource Assessment (2000) should be held in 1993.

The meeting will help to assess the outcome of the present global assessment, taking into account its strengths and weaknesses, and to elaborate recommendations for improvement of the work to be undertaken for the next Global Assessment.

The problem of the real integration of the tropical and temperate-zone parts into a single whole global assessment is still open, mainly for reasons of comparability of classification and definitions. This may well be one of the hardest points when elaborating recommendations for the scope and content of the 2000 Assessment.

Another important project endorsed by the Joint Working Party is the study on long-term historical developments of temperate-zone forests.

Long-term Changes in the Temperate Forest Resource and theFfactors Involved

The idea for such a study was born in response to discussions that took place in the preparatory meetings for the UNCED Conference, during which it was pointed out that compared with the spotlight on the obvious tropical deforestation, relatively little was known about the changes to temperate and boreal forests. The 1990 Assessment provides information on short-term changes (i.e. over the past decade) but this is insufficient for the purpose in mind.

The Joint Working Party agreed to a project to investigate the long-term historical changes to the forest resources and the factors involved in the industrialized temperate-zone countries.

Draft proposals for the project presented at the Working Party session suggested that the North American Forestry Commission of FAO, as well as IUFRO, should be invited to collaborate (TIM/EFC/WP.2/R.119, Annex III).

At present, there is an agreement with a consultant from France, Mr G Morin, on the "Preparation of a proposal for a study on long-term changes in temperate forests and the factors involved, including a model monograph on France". This proposal will be presented to the Timber Committee at its session in October 1992.

Probably the preparations for the next 2000 Forest Resource Assessment will produce further "supplementary" ideas for the ultimate benefit of the global forest resource.

Preparations for Kotka-II

The Ilvessalo Symposium offers a good opportunity to express sincere gratitude to our colleagues from Finland for their willingness and readiness to host the *ad hoc* FAO/ECE Meeting of Experts on Global Forest Resource Assessment in May 1993.

Proposals for the Provisional Agenda of the meeting are being discussed with FAO colleagues in Rome, and there will be an opportunity to discuss aspects of the *ad hoc* meeting during the Symposium this week and particularly on Friday.

No doubt "Kotka-II" will be another important step towards establishing a global forest monitoring system, based on the close ties of national inventories with the existing international structures of the Global Forest Resource Assessment.

CONCLUSION

Once again the importance should be stressed of national forest inventory activities, which are in present-day society the most reliable sources of information for international assessments and a solid basis for global monitoring of Forest Resources.

Our hosts deserve sincere thanks for their efforts in organizing this interesting symposium in memory of the noble founder of the activities in which we are now involved.

REFERENCES

UN-ECE/FAO, 1985. The Forest Resources of the ECE Region (Europe, the USSR, North America), United Nations, ECE/TIM/27, 223 p.

FINNIDA, 1987.Proceedings of the ad hoc FAO/ECE/FINNIDA meeting of experts on Forest Resource Assessment. Kotka, Finland, October 1987, FINNIDA MT 284, 433 p.

IUFRO/FAO, 1989Global Natural Resource Monitoring and Assessments: Preparing for the 21st century. Proceedings of the International Conference and Workshop, Venice, Italy, Vol.I–III, American Society for Photogrammetry and Remote Sensing , Bethesda, Maryland, USA, 1495 p

IIED, 1991Proceedings of the Technical Workshop to Explore Options for Global Forestry Management, Bangkok, Thailand, IIED, 349 p.

WSL/FNP,1991 Proceedings of the IUFRO Symposium "Forest Inventoriesin Europe with Special Reference to Statistical Methods", Birmensdorf, Switzerland, WSL/FNP, 239 p.

UN-ECE/FAO, 1992The Forest Resources of the Temperate Zones. Main Findings of the UN-ECE/FAO 1990 Forest Resource Assessment, United Nations, ECE/TIM/60. 32 p.

Legend
(Country groupings)

NORDICS	Finland, Norway, Sweden
N - W EUROPE	Belgium, Denmark, Iceland, Ireland, Netherlands, United Kingdom
C - E EUROPE	Austria, CSFR, France, Germany, Luxembourg, Poland, Switzerland
S - E EUROPE	Albania, Bulgaria, Cyprus, Greece, Hungary, Israel, Italy, Romania, Turkey, Yugoslavia
IBERIA	Portugal, Spain
NORTH AMERICA	Canada, USA
OCEANIA	Australia, New Zealand
"FORMER USSR"	comprises the Commonwealth of Independent States, including the Baltic States.

"OTHER FORMER USSR" excludes Belarus and the Ukraine.

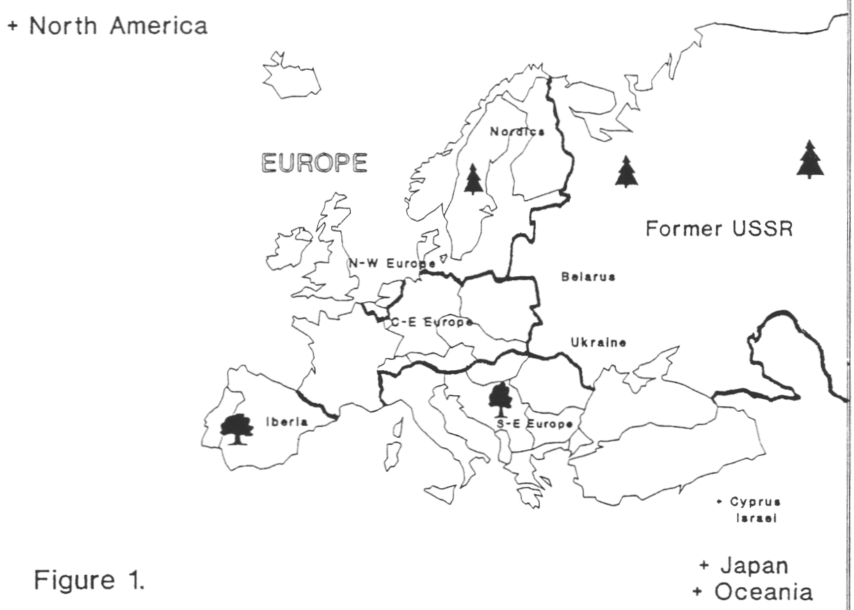
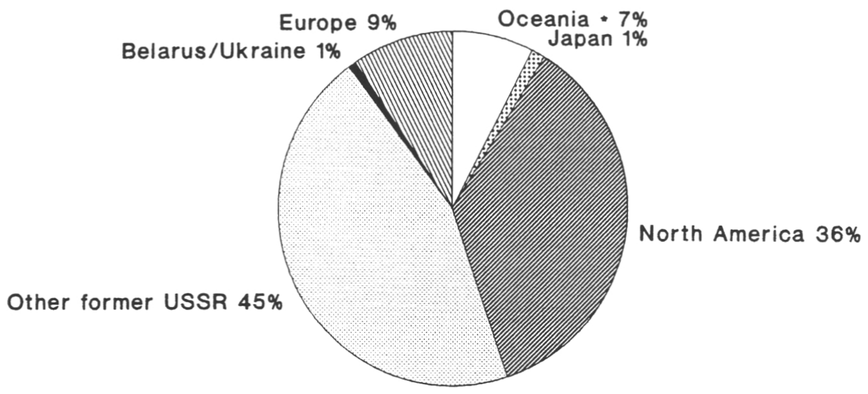


Figure 1.

Distribution of forest & other wooded land in temperate zone regions (percent of total)



Area: 2 064 million ha.

Figure 2.

Share of forest & other wooded land in total land area, around 1990

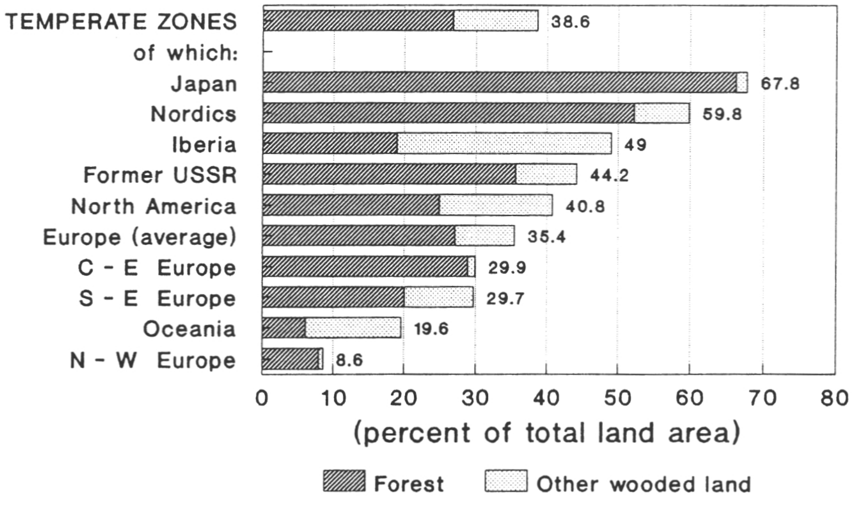


Figure 3.

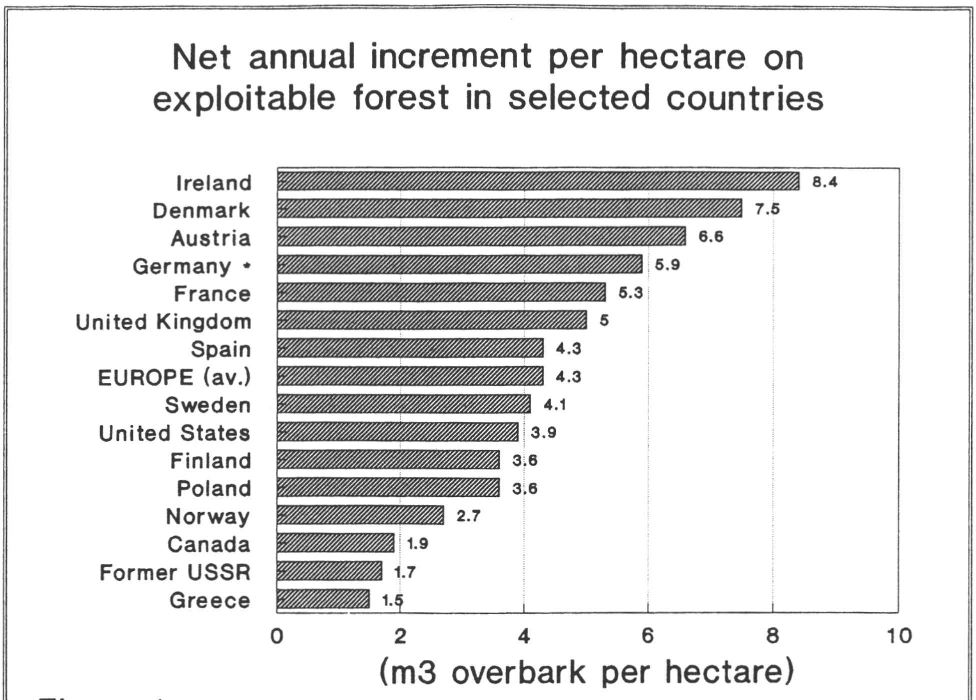


Figure 4.

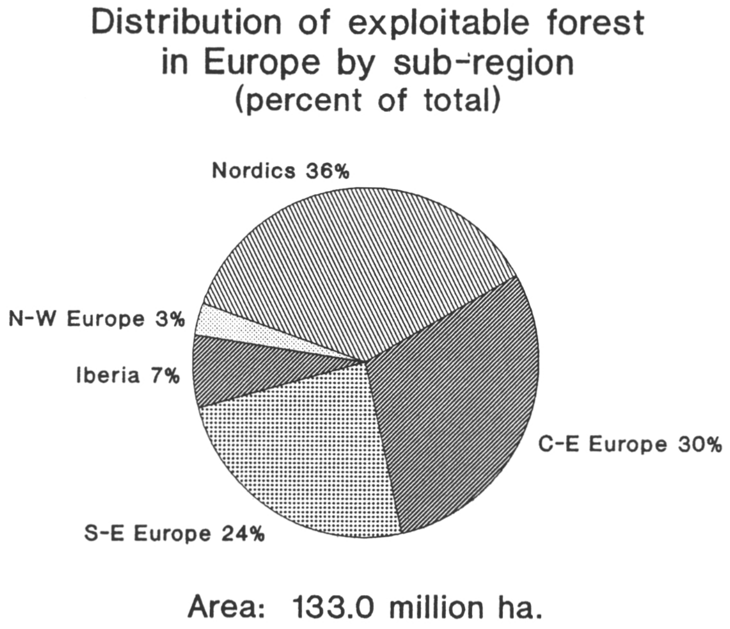


Figure 5.

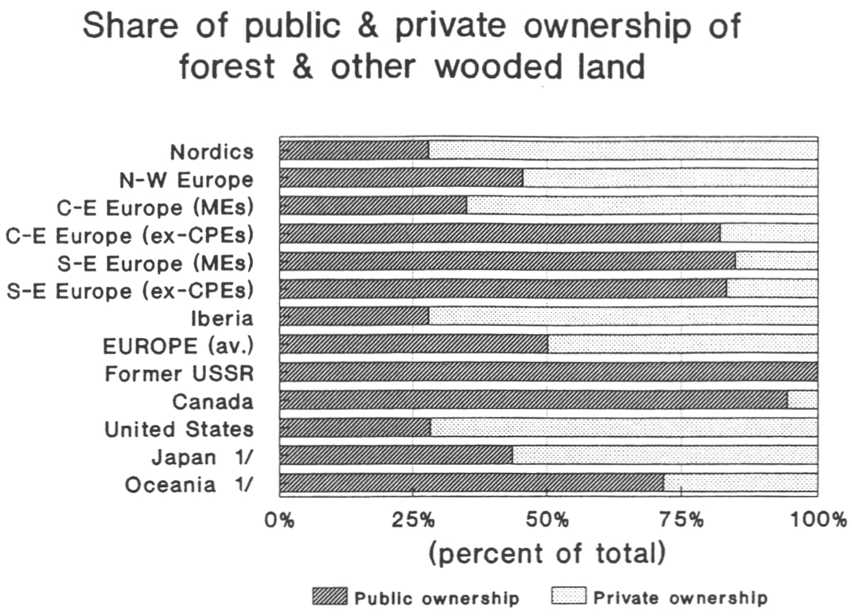
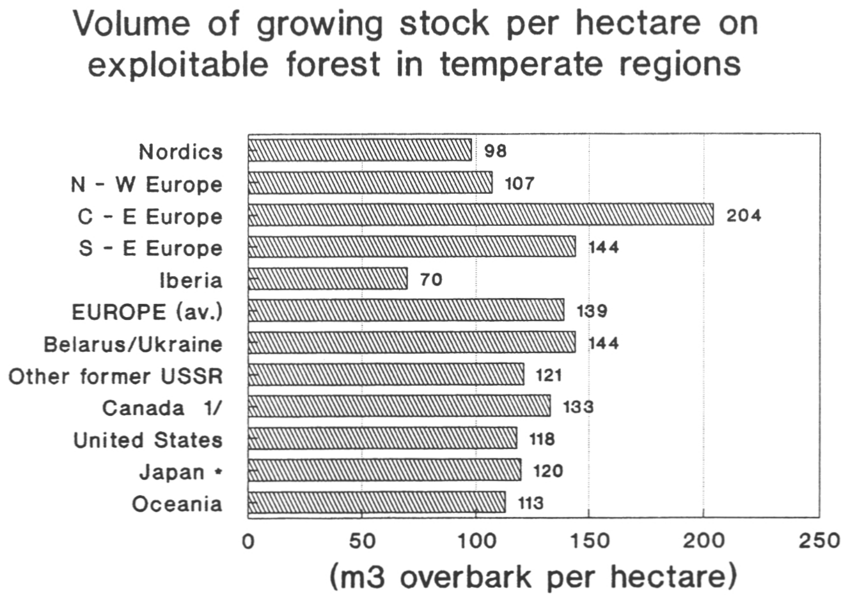


Figure 6. 1/ Forest only



1/ Underbark volume

Figure 7.

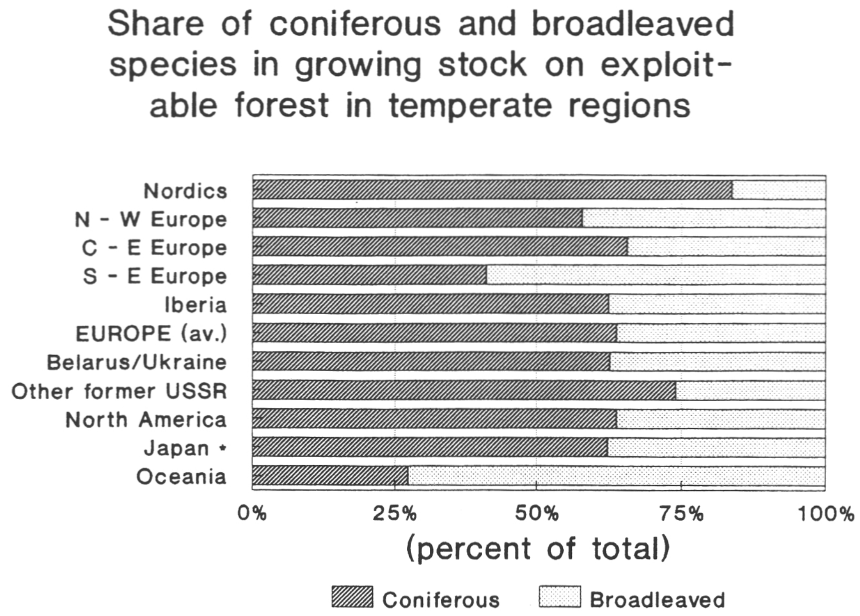
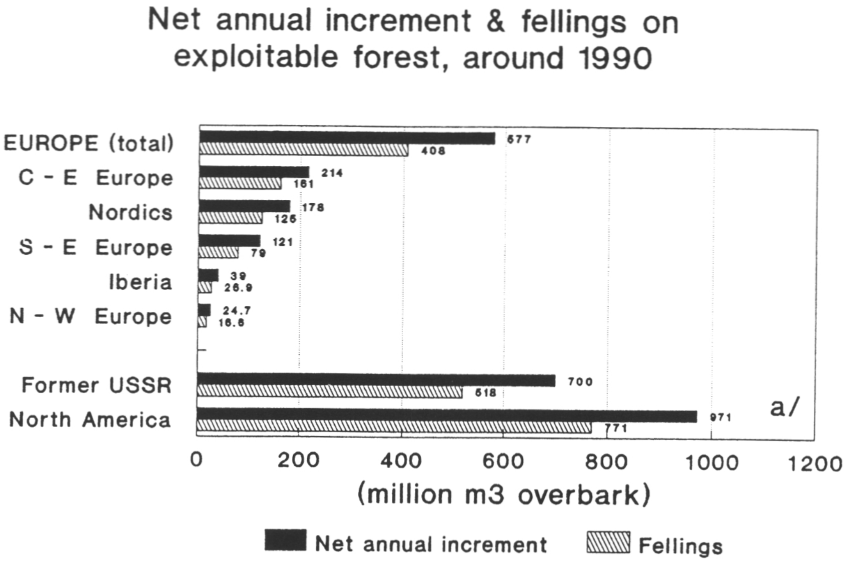
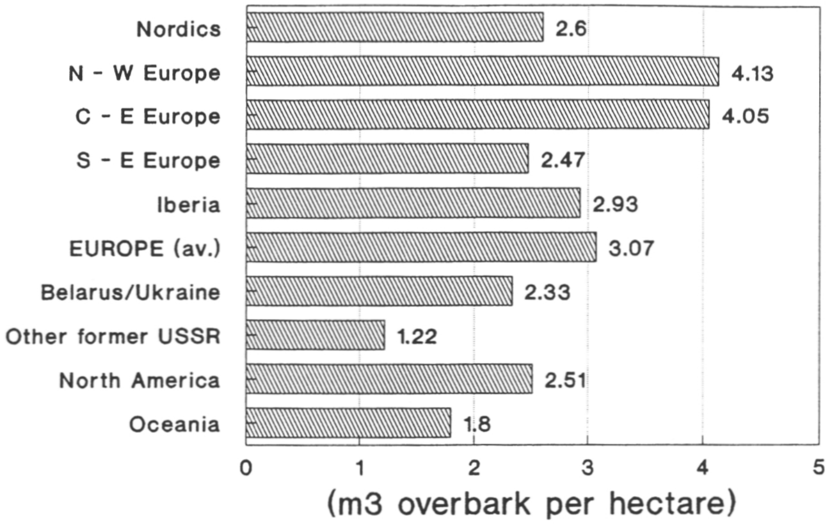


Figure 8.



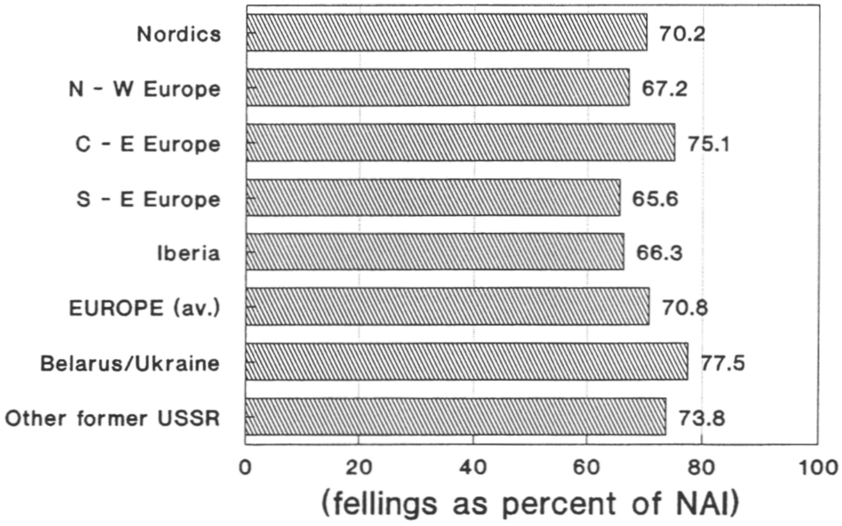
a/ Gross annual increment

Figure 9.



Wood harvesting intensity: fellings per hectare of exploitable forest

Figure 10.



Wood harvesting intensity: fellings/net annual increment ratio by sub-region

Figure 11.

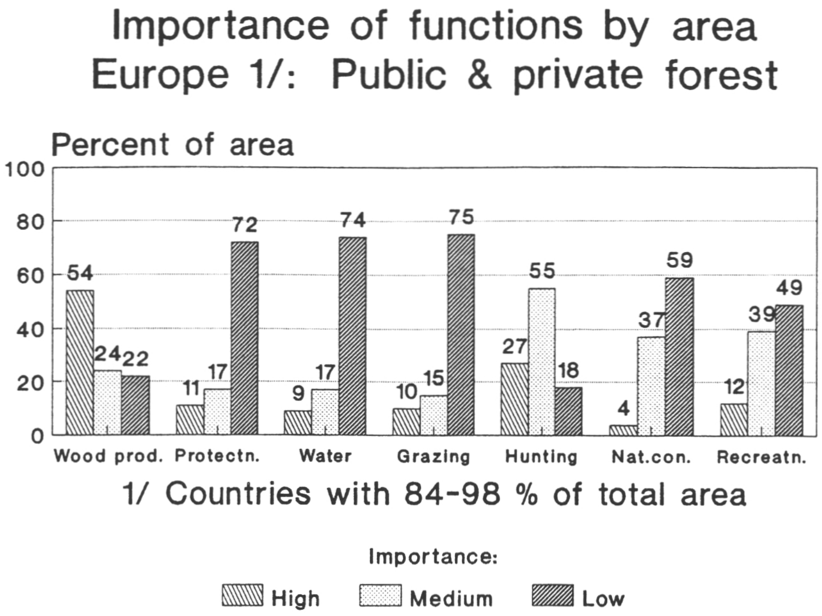


Figure 12.

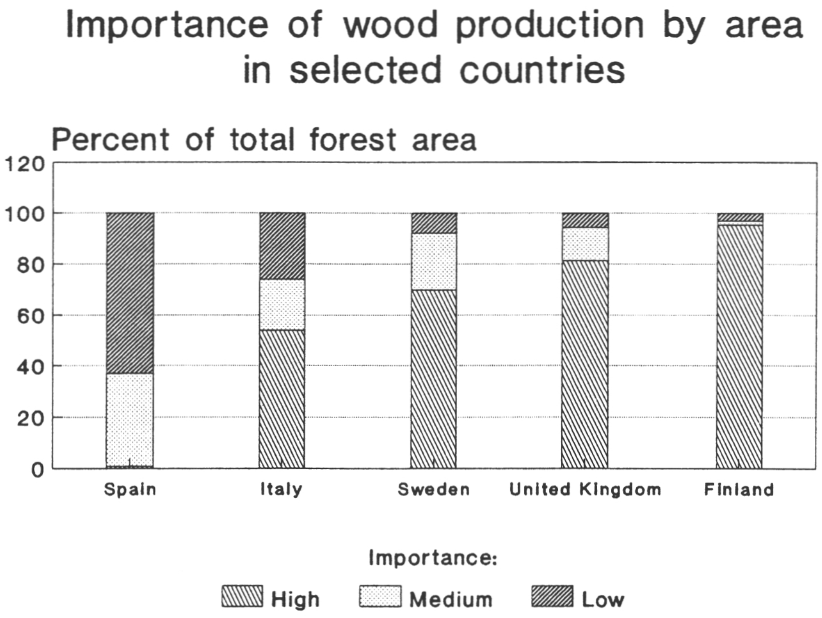


Figure 13.

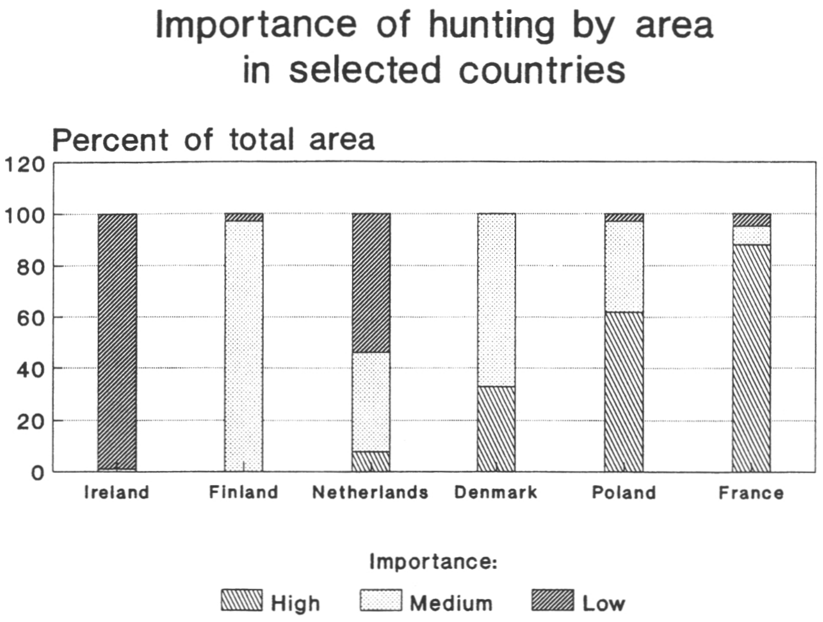


Figure 14.

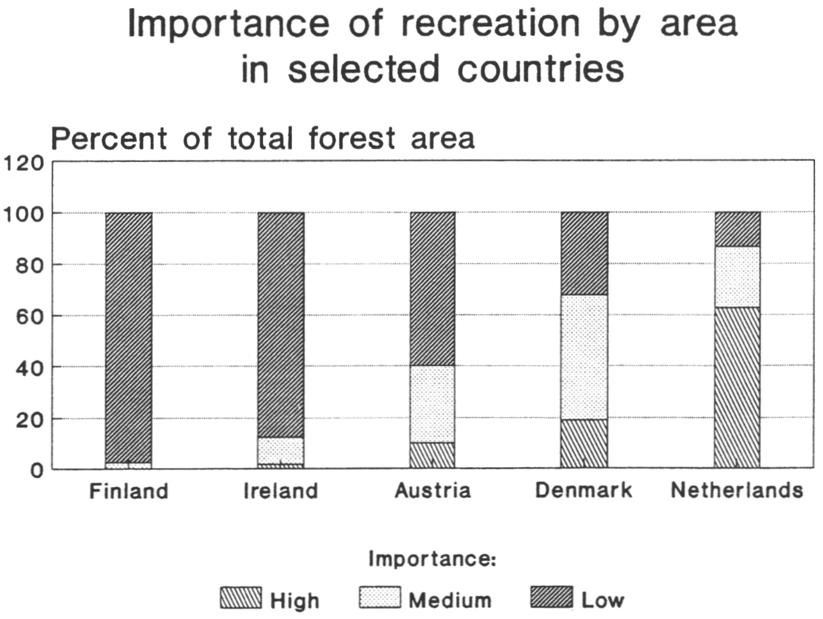


Figure 15.

MONITORING FOREST HEALTH

MONITORING FOREST HEALTH IN THE SWEDISH NATIONAL FOREST INVENTORY

Ulf Söderberg
Associate Professor
Department of Forest Survey
Swedish University of Agricultural Sciences
Umeå, Sweden

ABSTRACT

The Swedish National Forest Inventory (NFI) has since it started collected data of the state of the forests, which can be considered as one form of environmental monitoring. The last decades the work has widened to be directed to tasks of environmental monitoring. Special inventories of mosses and lichens for analysis of contents of heavy metals started in the 1970's followed in the eighties by the Forest Damage Inventory, connected to the European co-operation programme ICP-Forests. At that time the Site Survey was also introduced to the National Forest Inventory. This inventory consists of detailed soil and vegetation descriptions and soil samples for chemical analysis. Together with the NFI data this data constitutes a valuable database for environmental monitoring and analysis. Other parts of the inventory as the registration of damage and grazing on trees and bushes by moose, the occurrence of dead and wind-thrown trees and the increment data from the sample trees are substantial in the monitoring of forest health.

New methods based on needle sampling of sample trees and analysing for amino acids can be introduced as well as methods of remote sensing can be valuable for certain moments of environmental monitoring. The use GPS-techniques as well as GIS systems will be important tools in the analysis of environmental monitoring.

Keywords: forest damage, defoliation, heavy metals, soil samples

INTRODUCTION

With the changes of the environment of nature over time, the requirements for knowledge of the changes is increasing. To meet these problems with effective efforts one need to know the character, size and geographical distribution of the changes. A lot of work in this direction is already done to follow this changes in research projects and by different authorities (organisations). These efforts are not sufficient but more information has to be collected.

The collection of information from the field is expensive and time consuming. Therefore this work should be carefully planned and effectively organized. An effective way to reach this is to use an already existing field organisation to get the information wanted. One way to get this is to use the organisation of the National Forest Inventory. The National Forest Inventory has got a great potential to describe and collect data not only about the forests but also about the nature and environment in a wider sense.

Some of the advantages of using the NFI in environmental monitoring are the following:

- a solid statistical design with objective sampling which annually covers the entire country implies that collected data can be generalized to the total investigated population.

- the inventories are continuous and long-termed which makes it possible to study long time series.
- the inventory of soil, vegetation, shrub layer, tree layer and land use on the same plots results in that data from a great part of the ecosystem can be connected.
- the collected data are position-determined and can therefore be treated together with other positioned data such as deposition, information from remote sensing
- new variables can be introduced with a low marginal cost.
- the organisation is effective and the field crews have a great experience of the different parts of the inventory.

Together with the site survey the NFI gives good possibilities for environmental monitoring of the land ecosystem of Sweden (in the meaning of establish the state and changes of the environment). Since the inventories are non-experimental they are not suitable for studies of cause-effect relations. To do this carefully controlled experiments are needed.

METHODS

The NFI is an annual inventory covering the entire country, the design of which is systematic cluster sampling, where the cluster is a square (tract) with a side length of 400 –1 800 m. About half of the tracts are permanent, while the rest are temporary. Along the sides of the square, 3-5 plots with radii of 10 metres on permanent tracts and 7 metres on temporary tracts are laid out systematically. The size of the square and the number of plots varies between the survey regions (Figure 1). The tracts are largest in the north and decrease towards the southern parts of the country. On the plots stand and site characteristics as well as silvicultural treatments carried out on the plots are described in detail. Sample trees are selected, with higher probability for large trees, and no sample trees of diameter less than 4 cm are taken. A more detailed description of the National Forest Inventory is found in Ranneby et al. 1987.

The methods used varies with the kind of variable and aim of the registration in question from visual judgement to measurements and subsampling for further analysis.

Figure 1. Division into survey regions in the NFI.

The Forest Damage Inventory

This inventory is completely incorporated with the NFI and the assessments are made by the NFI field crews on the sample trees from the NFI. Besides needle loss other variables are recorded, describing the crown injury type, proportion of secondary shoots and the exposition of the plot. The Forest Damage Inventory has been carried out without any major changes since 1984. In total about 17 000 trees are assessed annually.

The assessment is restricted to dominant, co-dominant and open-grown trees together with seed trees and standards. Only ordinary sample trees of Scots pine and Norway spruce in addition to supplementary sample trees of Norway spruce are assessed. The estimation of defoliation was in 1985–1989 classified into 10%-classes and is related to an imaginary full needle set-up for the individual tree. The assessment was done in 20%-classes in 1984 and in 5%-classes from 1990.

In 1990 an inventory of defoliation on birch (Betula ssp.) was set up for southern Sweden and at the same time a net of reference plots were laid out throughout the country. This inventory was followed by an inventory in 1991 of central Sweden and in 1992 of northern Sweden while the reference plots were inventoried annually. The inventory is made on a stratified sample of permanent plots of the NFI and is performed by two separate field crews with special training on the procedure of assessment.

The Site Survey

This new site survey is a methodological development of earlier surveys of this type, performed in connection with former NFI (Troedsson 1966). The site survey comprises measurements of the following characters: ground vegetation, humus layers, soil depth, texture and hydrology. Further, the humus layer and mineral soil are sub-sampled. The samples are transported to laboratory for analysis of nitrogen, carbon, pH, exchangeable cations and aluminium. For mineral samples of 50 cm depth a total analysis is made (ICP-analysis). In total the survey has gathered data from about 18 000 permanent plots on forest land. The scientific guidance of the survey design and development lies at the Department of Forest Soils, Swedish University of Agricultural Sciences.

The Moss Survey

The moss survey is carried out every fifth year since 1975 at the request of the National Swedish Environmental Protection Board. Samples of Hylocomium splendens and Pleurozium schreberi are taken at plots of the NFI. The samples are sent to a environmental bank for saving and a part of the samples are used for analysis (Monitor 1990).

Needle Sampling Survey

In a pilot study still in progress needle samples from Norway spruce are collected from some of the permanent plots of the NFI (Nordén 1991). The needles are analysed for the contents of nutrients and the amino acid arginine. The results are then combined with data concerning tree growth and defoliation, as well as with data describing the site.

RESULTS

The National Forest Inventory

The data of the NFI are more or less connected to the health of the forests. Some variables are completely dedicated for this purpose, such as recording of damages of sample trees and stands, moose grazing on young pine stands and registration of dead trees. Others are more related to the state of forests in terms of volume, age and growth. The collection of increment cores on sample trees are valuable of several reasons. The trends of tree growth can be analysed as well as relation of growth to other factors such as defoliation and deposition.

A study on the relation between defoliation and increment shows a decreasing growth with increasing defoliation for both Norway spruce and Scots pine (Söderberg 1991). The relation between defoliation and increment is relatively stable for the different survey regions (Figure 2).

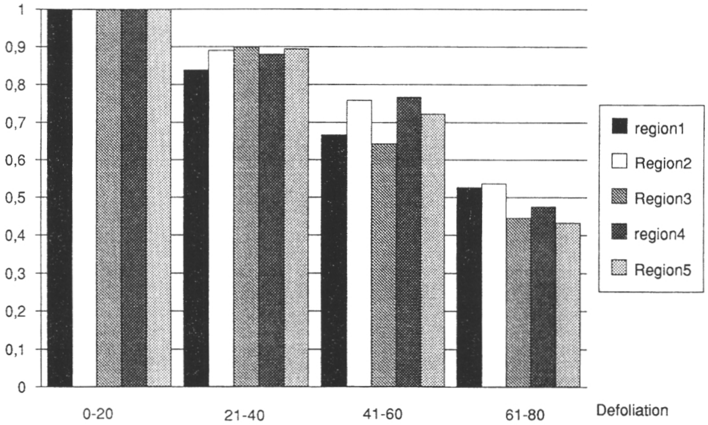


Figure 2. Relative increment of Norway spruce of different defoliation for the five survey regions in Sweden.(class 0–20% defoliation is reference)

Another example of results from the NFI are the state of young pine forests as regards moose grazing, which has been a big problem in Sweden the last decades. In Figure 3 the development of the area damaged by moose for different parts of Sweden is shown. The degree of damage is recorded in five classes from undamaged to severely damaged.

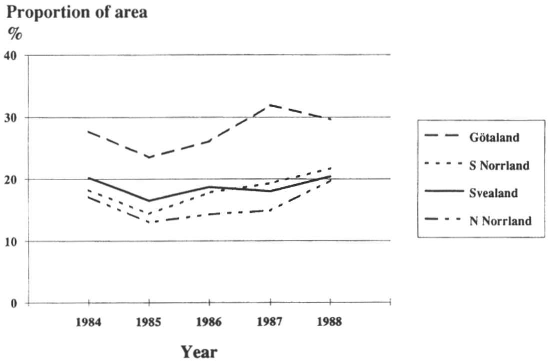


Figure 3. Proportion of area of young pine forests (mean height 0.5–1.5 m) damaged by moose for different parts of Sweden (from Kempe 1990).

The Site Survey has as an example resulted in a geochemical atlas of Swedish forest soils (Melkerud, P-A, Olsson, M. & Rosén, K. 1992). The geographical distribution and frequency of soils with different percentages of potassium is shown in Fig 4.

The results of the Forest Damage Inventory shows that no significant change of the state of the forests has occurred since 1984. However, there is a variation beween years and a tendency to an increased defoliation during the last years. The geographical pattern of the degree of defoliation shows that the most severe degree of defoliation occurs in the northern and southwestern parts of the country (Fig 5).

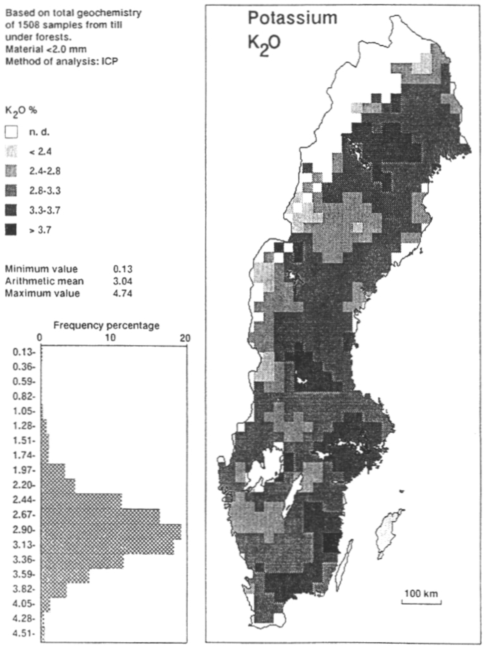


Figure 4. The contents of potassium in forests soils in Sweden (from Melkerud et al. 1992)

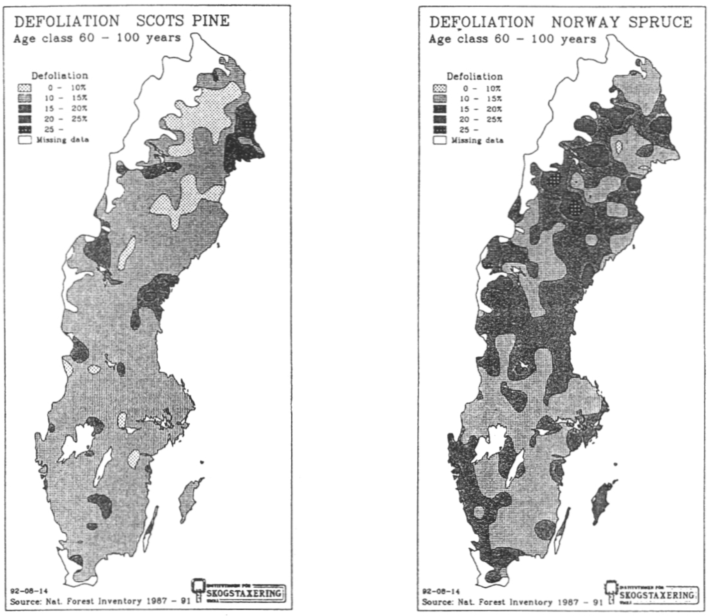


Figure 5. The geographical pattern of the degree of defoliation of Scots pine and Norway spruce in Sweden.

DISCUSSION

The possibilities of using a National Forest Inventory in monitoring purposes seems infinite. According a study based on an inquiry the suggestions of various monitoring tasks were numerous (Olsson, D. & Wramner, P. 1988). Of course, the present design of the NFI is not suitable for all kind of monitoring. However, many of the suggestions could easily be included in the present inventory design. There are also possibilities to adapt the inventory to special studies or to set up separate field crews for special surveys.

Above only a few examples of results from the NFI and related surveys were given. Much more has been done and could be done. The future will give increased possibilities to do valuable analysis if the planned development of the NFI and the connected surveys can be fulfilled. The use of global positioning systems, remote sensing techniques, transmission of databases with position-determined data as well as increased cooperation on the national and international level seems to be the means to improve future monitoring.

REFERENCES

Kempe, G. 1990. Älgens skadegörelse på tallungskogen. Sveriges lantbruksuniversitet, Skogsfakta, Inventering och ekonomi nr 24.

Melkerud, P-A, Olsson, M. & Rosén, K. 1992. Geochemical Atlas of Swedish Forest Soils. Swedish University of Agricultural Sciences, Department of Forest Soils, Report 65.

Monitor 1990. Environmental monitoring in Sweden. Swedish Environmental Protection Agency, 177pp.

Nordén, L-G & Ericsson A. 1991. Mineral nutrients and amino acids in needles as indicators of tree vitality? Proceedings from IUFRO Workshop on Monitoring Air Pollution Impact on Permanent Sample Plots, Data Processing and Results Interpretation. Department of Ecology Monitoring, Forestry and Game Management Research Institute, Jíloviště- Strnady, 15604 Prague, Czechoslovakia.

Olsson, D. & Wramner, P. 1988. Breddning av Rikskogstaxeringen. –En studie över förutsättningar att följa miljöförändringar mm. Sveriges lantbruksuniversitet, Inst för skogstaxering, arbetsrapport 4. 79pp.

Ranneby, B. Cruse, T. Hägglund, B. Jonasson, H. & Swärd, J. 1987. Designing a new national forest survey for Sweden. Studia forestalia Suecica, no 177, 1987.

Söderberg, U. 1991. The relation between increment and defoliation for Scots pine and Norway spruce in Sweden. Proceedings from IUFRO Workshop on Monitoring Air Pollution Impact on Permanent Sample Plots, Data Processing and Results Interpretation. Department of Ecology Monitoring, Forestry and Game Management Research Institute, Jíloviště- Strnady, 15604 Prague, Czechoslovakia.

Troedsson, T. 1966. Skoglig markkartering som grund för bedömning av bördigheten. Svensk lantmäteri Tidskrift 58:1. 37pp.

SAMPLING DESIGN OF THE U.S. NATIONAL FOREST HEALTH MONITORING PROGRAM

Charles T. Scott, David L. Cassell, and John W. Hazard
USDA Forest Service
Delaware, OH, USA
METI Environmental Services
Corvallis, OR, USA
Consulting Service
Bend, OR, USA

ABSTRACT

The USDA Forest Service, U.S. Environmental Protection Agency, state, and other agencies initiated the Forest Health Monitoring (FHM) Program in 1990. The objectives are to monitor the current status and trends in forest ecosystem conditions in response to pollutant exposure. The FHM Program is part of a larger Environmental Monitoring and Assessment Program (EMAP). The sampling design used in FHM is based on the EMAP grid of 12,600 hexagons across the continental United States. At each grid point, a 40-km^2 hexagon is to be characterized by a variety of remotely sensed and map-based descriptors. A cluster of plots is visited on the ground in each hexagon. The cluster is composed of a series of nested fixed-radius plots at four points. Clusters are located on both forest and nonforest lands. Observations are made on site conditions, soils, tree size and visual symptoms, foliar chemistry, and vegetative structure. A pilot study of 40 clusters in 1990 has shown the cluster design to be adequate and efficient for a variety of attributes.

MONITORING NEEDS IN THE UNITED STATES

Change in our nation's forest resources is anticipated as a result of atmospheric pollution and deposition. Because the timing, extent, and economic impacts of this change are unpredictable, the USDA Forest Service (USFS) and the U.S. Environmental Protection Agency (EPA) decided to develop a system to detect the response of our forest resources to human activity. The objectives are to:

1. Statistically estimate the current status and extent as well as changes in indicators of the condition of forest ecosystems, both at regional and national levels.
2. Monitor indicators of pollutant exposures and habitat condition and seek associations between human-induced stresses and forest ecosystems.
3. Provide yearly summaries and periodic interpretive reports on status and trends for resource managers and the general public

This detection-level monitoring system is designed to locate problems but will fall short of attempting to establish cause-effect relationships. However, the monitoring will aid in guiding further evaluation and research.

HISTORY OF FOREST HEALTH MONITORING

The monitoring system evolved from the efforts of two federal agencies and the urging of state forest agencies. While the USFS and state agencies were developing a monitoring system for forest health in the northeast, the EPA was independently developing a monitoring system for all natural resources. These two efforts were then combined.

Much of the sampling design of the monitoring system was developed by the EPA's Environmental Monitoring and Assessment Program (EMAP). EMAP was developed as a nationwide network to look at all natural resources that could be affected by atmospheric pollution and deposition. From the beginning, the EPA recognized the need to involve other federal agencies in this massive effort.

The USFS initiated a similar program on all forest lands by congressional mandate with the encouragement of state forest agencies, particularly in the northeastern United States. Thus, the USFS and EPA combined efforts to form the Forest Health Monitoring (FHM) Program (Brooks et al. 1991a). FHM was initiated in late 1989 with first field season in 1990 in the six New England states (Brooks et al. 1991b). In 1991, six states along the eastern and southern coasts were added. In 1992, two states were added in the West.

FHM is conducted as a cooperative effort of the USFS, EPA, and state agencies, plus other governmental agencies including the Tennessee Valley Authority and the USDI Bureau of Land Management. The USFS and EPA have joint responsibility for administration, funding, design, training, quality control, technical support, data processing, and reporting. State agencies provide most of the field personnel.

EMAP DESIGN

EMAP designers worked with geographers to develop a grid-based design that can be used to cover the globe. A systematic, triangular grid was chosen to ensure a representative sample and to minimize variance. It also makes it possible to define and develop efficient estimates for various subpopulations of interest. The grid can be combined with auxiliary information to develop post-stratification estimators for a variety of classifiers, now and in the future (Overton et al. 1990)

The triangular grid results in a network of hexagons that cover the United States and can be extended to the globe. The grid density can easily be adjusted to the desired sampling intensity of any special-interest subpopulation. The base grid has 12,600 hexagons covering the continental United States. Of these, approximately 4,500 contain some forested land. The baseline grid centers are 27 km apart, and each is at the center of a 635 km^2 hexagon. A 40 km^2 hexagon surrounding the grid point was chosen for more detailed investigation. One-fourth of the grid is visited every year, resulting in a four-year measurement cycle. This is referred to as an "interpenetrating" design, because the sample taken each year covers the same area as the year before. The subgrid is offset from one year to the next and returns to the initial location in the fifth year. Each year's sample lies on a regular triangular subgrid of the base grid and thus results in a representative sample of the population of interest.

This grid is used by each of the other federal agencies with whom the EPA is cooperating. EMAP has been divided into the following resource groups:

- Estuaries
- Inland Surface Waters
- Great Lakes
- Wetlands
- Forest
- Agroecosystems
- Arid Lands

Each group is approaching the problem using the base grid as the sampling frame. Sampling within hexagons differs among resource groups. Common to all groups is an effort to characterize each 40-km^2 hexagon. This characterization includes most information that can be gleaned from maps, aerial photographs, and satellite imagery, as well as pollution and climate data. Because this characterization alone will take at least 10 years to complete for the 12,600 hexagons, using USFS Forest Pest Management imagery or reducing the area characterized are alternatives to speed the process.

As noted earlier, the primary purpose of EMAP is to detect resource problems. Once a problem is detected, a more intensive evaluation effort is initiated to identify possible causes. If additional efforts are required, a research effort is initiated on long-term ecological research sites. Thus, FHM has three levels of monitoring.

FOREST HEALTH MONITORING DESIGN

The sampling design was developed primarily by the design team for EMAP. The cluster design was initially developed by the USFS and was jointly adapted to the FHM indicators. The EPA and the USFS worked together on a test of the design.

Sampling Design

The sampling design for FHM follows the EMAP grid. A single sample point is selected near each hexagon center, resulting in a systematic sampling design. To correct for land-use changes over time, sample clusters are systematically located on both forest and nonforest lands. Plot clusters that are entirely nonforest are verified in the field, but no additional data are collected. Such sample locations are revisited in four years to determine if conversion to forest land has occurred.

Forested clusters are visited annually for visual symptoms of damage and on a four-year interpentrating basis for mensurational data, such as land-use change and growth. To regain some of the annual detail and avoid annual field visits, the USFS Forest Pest Management unit is investigating the use of airborne-video methods in conjunction with the landscape characterization component of EMAP. With either the annual or interpenetrating design, mensuration variables such as tree diameter are to be taken every four years. Soil and site characteristics are taken once during the initial survey and a subset of these measurements may be taken at longer intervals.

Cluster Design

When the cluster or plot design was being developed, both fixed-radius plots and Bitterlich variable-radius plots (prism points) were considered. Fixed-radius plots were chosen, because Scott and Alegria (1990) found that they gave more precise estimates for most of the trend attributes that are of interest in FHM. Because clusters are more efficient for large-scale surveys, a cluster of four concentric fixed-radius plots was chosen (Scott 1992). Three sample points are equally spaced at 36.6 m from the center point (figure 1). For trees greater than 12.7 cm in diameter at breast height (dbh), a tree plot of 168.1 m^2 is used. Seedlings and saplings are measured on a 13.5-m^2 regeneration plot which is offset 3.66 m east of each sample point to avoid trampling.

Branch and root samples are taken on trees outside each tree plot. The total area within this sample tree plot is 0.1 ha. This includes the tree plot area, but no branch or root samples are collected within the tree plot, only the annulus surrounding it. Three soil pits are dug and characterized in the area between the three exterior sample points.

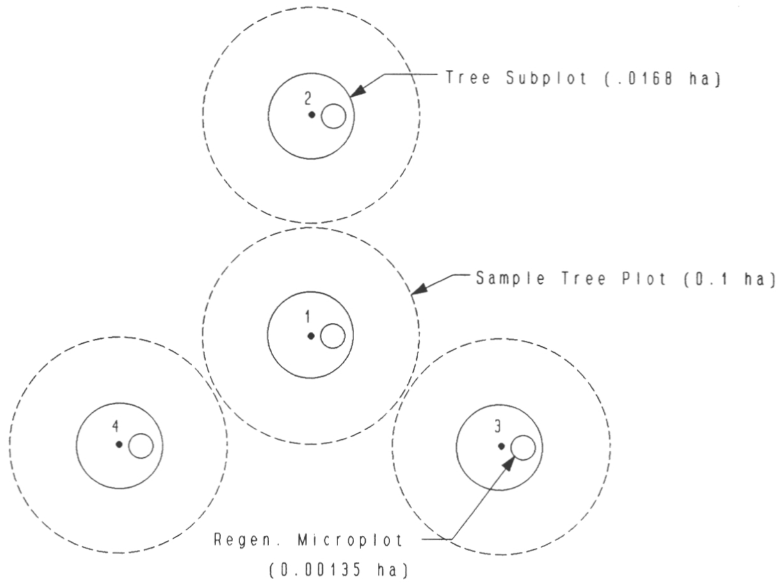


Figure 1. U.S. Forest Health Monitoring plot cluster

Sampling at the Forest Edge

FHM uses a different approach to handling forest boundaries than has been used in the past. For such a critical national survey, criticism arose over the use of current practices, so a system was developed that avoids boundary bias and the use of estimators which eliminate boundary bias (Gregoire and Scott 1991).

Clusters are placed systematically across the landscape and visited to see if any portion of the cluster is forested. Plots are then classified into cover condition classes–combinations of land use, forest type, stand size (structure), and disturbance. Stand boundaries falling within plots are mapped (figure 2). Trees are assigned individually to a condition class. A forthcoming paper will describe the details of this method

This method avoids bias in all tree attributes such as numbers of trees, basal area, and volume. It also avoids the bias of combining information from two or more cover condition classes into a single classification, such as has been used in the past. For those estimates that include cover condition class, this method requires that field crews be able to recognize when boundaries occur and that they correctly assign a cover condition class to each. Because clusters do not always fall in a single condition or even completely within forest land, modeling across plot clusters becomes more complicated. Also, for certain types of analyses, estimation will require the use of unequal probability estimators, because clusters with only a portion of their area in the population of interest will have different inclusion probabilities than those which are totally within the population.

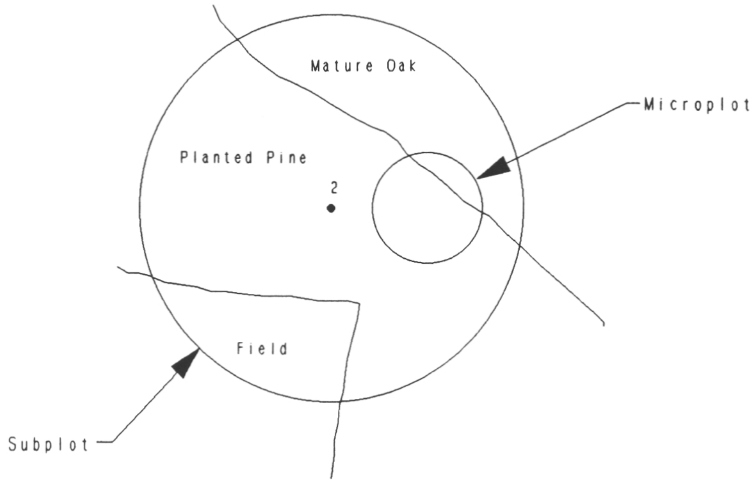


Figure 2. Mapped stand boundaries falling within a tree subplot

Measurements

The measurements taken are divided into three groups. As part of the first measurement of a cluster, the site is characterized. These attributes, such as its topography and other stable characteristics, are listed in Table 1. The periodic measurements (Table 2), such as cover condition class and tree history and diameter, are taken every four years starting with the first measurement. Measurements that are currently annual in some states (Table 3) generally are limited to visual symptoms of damage and may be observed remotely in the future.

Table 1. Attributes observed only at initial measurement of FHM cluster

	Location Data	
Elevation	Terrain Position	Percent Slope
Aspect	Microrelief	

Table 2. Attributes observed periodically (four-year cycle) for FHM

	Condition Data	
Condition Class	Land-Use Class	Forest Type
Stand Origin	Stand Size	Past Disturbance
Disturbance Year		
	Point Level Data	
List of Subplot Conditions	Subplot Center Condition	Microplot Center Condition
	Boundary Data	
Plot Type	Condition Beyond Boundary	Left Azimuth
Left Distance	Corner Azimuth	Corner Distance
Right Azimuth	Right Distance	
	Microplot Data	
Percent Moss	Percent Ferns	Percent Herbs
Percent Shrubs	Percent Seedlings	
	Seedling Data	
Species	Condition Class	Crown Class
Seedling Count	Crown Vigor	
	Sapling Data	
Tree Number	Old Tree History	Current Tree History
Species	Old Diameter at Breast Ht.	Diameter at Breast Height
Horizontal Distance	Azimuth	Mortality Year
Condition Class	Crown Class	Crown Vigor
Crown Ratio	Damage	Damage Location
Probable Cause	Cause of Death	Notes
	Tree Data	
Tree Number	Old Tree History	Current Tree History
Species	Old Diameter at Breast Ht.	Diameter at Breast Height
Horizontal Distance	Azimuth	Mortality Year
Year Fell to Ground	Condition Class	Crown Class
Crown Ratio	Crown Diameter	Crown Diameter II
Crown Density	Crown Dieback	Foliage Transparency
Damage	Damage Location	Probable Cause
Cause of Death	Notes	

Table 3. Attributes observed annually for FHM

	Sapling Data	
Current Tree History	Mortality Year	Crown Vigor
Crown Ratio	Damage	Damage Location
Probable Cause	Cause of Death	
	Tree Data	
Current Tree History	Crown Ratio	Crown Diameter
Crown Diameter II	Crown Density	Crown Dieback
Foliage Transparency	Damage	Damage Location
Probable Cause	Cause of Death	

CLUSTER DESIGN ASSESSMENT

A pilot study was conducted to evaluate the feasibility and efficiency of the cluster design and to evaluate various potential indicators of forest health (Riitters et al. 1991). Twenty clusters were located in each of two forest type groups (deciduous versus coniferous). Intensive measurements were taken to assess both accuracy and spatial variability.

Using multistage sampling optimization formulas (Cochran 1977), optimal number of sampling and subsampling units were developed, thus checking for adequacy of sample and sampling unit design. Also, a spatial analysis was conducted on photosynthetically active radiation (PAR), soils, and foliage structure grids of measurements using semi-variograms. The design proved adequate and efficient for the variety of variables observed.

The number and size of the plots were more than adequate for most of the attributes observed. Two sample trees on each of three to four sample tree plots proved sufficient for obtaining branch and root samples. Two to three soil pits were found to be adequate. Foliar chemistry proved variable, requiring five to six branches from each of two trees for a total of 15 to 30 branches per species.

The optimal cluster design showed little sensitivity to measurement and within-cluster travel costs. Rather, it changed primarily as a function of the time and expense of traveling to and from the cluster location. This is true of most regional surveys (Scott 1992).

CONCLUSIONS

The pilot study indicated that this cluster design is appropriate for a variety of measures of forest ecosystem health. Research will continue on the efficiency of this cluster design, extending to different forest types and other regions of the country. While no single cluster design will be optimal under all conditions, the current design will be the standard, with the possible exception of the western areas where individual trees can be as large as the plots.

Because the U.S. National Forest Health Monitoring sampling design is simple, it is robust to changing demands over time. The analysis is simplified due to the use of simple random sampling and fixed-radius plots. The estimates of change over time are improved by remeasuring the same clusters, by adding no new clusters, and by using fixed-radius plots. The sampling and cluster designs have proven themselves in the field and in the analysis phase over the past two seasons. We have every expectation that the program will continue for many more years and will be extended over the entire United States.

REFERENCES

Brooks, R.T., Millers, I., Dickson, D.R., 1991a: Forest Health Monitoring in the United States: the 1990 experience in New England. *In* IUFRO and ICP-Forests Workshop on Monitoring Air Pollution Impacts on Permanent Sample Plots, Data Processing, and Results Interpretation. 2–6 September 1991; Prachatice, Czechoslovakia. pp. 12–21.

Brooks, R.T., Miller-Weeks, M., Burkman, W., 1991b: Forest Health Monitoring: New England, 1990. USDA Forest Service, Northeastern Forest Experiment Station, Radnor, PA, NE-INF–94–91. 9 p.

Cochran, W.G., 1977: *Sampling Techniques*, third edition. John Wiley and Sons, New York, 428 p.

Gregoire, T.G. and Scott, C.T., 1990: Sampling at the stand boundary: A comparison of the statistical performance among eight methods. In Research in Forest Inventory, Monitoring, Growth and Yield. IUFRO World Congress, 5–11 Aug. 1990; Montreal, Canada: Virginia Polytechnic Institute and State University, Blacksburg, VA, Publ. FWS-3-90. pp. 78–85.

Overton, W.S., White, D. and Stevens, D.L., 1990: Design report for EMAP, Environmental Monitoring Program, Part 1. Draft report.

Riitters, K.H., Papp, M.L., Cassell, D.L., Hazard, J., 1991: Forest Health Monitoring Plot Design and Logistics Study. U.S. Environmental Protection Agency, Research Triangle Park, NC, EPA/600/S3–91/051.

Scott, C.T.; Alegria, J., 1990: Fixed– versus variable–radius plots for change estimation. In LaBau, Vernon J. and Cunia, Tiberius, eds. Symposium on State of the Art Methodology of Forest Inventory, Workshop Proceedings. 30 July – 5 August 1989; Syracuse, NY: USDA Forest Service, Pacific Northwest Forest and Range Research Station, Portland, OR, General Technical Report PNW–263, pp. 126–132.

Scott, C.T., 1992: Optimal design of a plot cluster for monitoring. *In* IUFRO S.4.11 Conference: The Optimal Design of Forest Experiments and Surveys, 10–14 September 1991; Thames Polytechnic Institute, London (in press).

PROGRESS IN DEVELOPING A FOREST HEALTH MONITORING DATA BASE FOR USE IN BOREAL FOREST SCIENCES

Vernon J. LaBau
USDA Forest Service
Anchorage Forestry Sciences Laboratory
Anchorage, Alaska, USA

ABSTRACT

In July, 1991, at a meeting of forest scientists from most of the boreal forest nations of the world, the International Boreal Forest Research Association was formed. One of the areas of emphasis at that meeting was to pursue the idea of establishing a set of forest health monitoring "indicators" that would be studied across the boreal forests of the world.

A proposal for such cooperation between the governments of Finland and the United States was in process during 1991. Subsequently, interest was also expressed by scientists from Russia, Canada, and Scandinavia to extend such an agreement to include those governments, thus encompassing all nations with boreal forests.

Considerable progress has been made in the past year in that regard, supported by a $5,000 grant from the U. S. Office of International Cooperation and Development. This presentation highlights that international effort and its progress.

Keywords: Forest health monitoring, boreal forests, international

INTRODUCTION

As I make my presentation today, I will be wearing two hats. First, I am a co-chairman of the International Union of Forest Research Organization's S4.02.06 (Boreal Forest Data) Working Party, so I have a responsibility in this regard. I am also the United State's Deputy Coordinator for the International Boreal Forest Research Association (IBFRA). IBFRA was formed at a meeting of boreal forest scientists and managers held June 24–28 in Kiev and Uzhgorod, Ukraine.

The Ukraine meeting was called in response to recommendations of the "White Sea Declaration," a document which evolved from an International Symposium on "Boreal Forests: State, Dynamics and Anthropogenic Influences," held in Archangelsk, Russia in July of 1990. One of the recommendations of that White Sea Declaration called for the "development of an international project on Boreal Forests in the Contemporary World." This was subsequently enacted at the Kiev/Uzhgorod meeting in the form of IBFRA.

One of the recommendations of the meeting in 1991 in Ukraine was that IBFRA pursue a cooperative agreement on a set of forest health monitoring (FHM) "indicators", that is a FHM data base, that could be utilized across the boreal forests of the world. This implied a cooperative effort between the forest scientists and managers from Canada, Finland, Norway, Sweden, Russia, and the United States.

I agreed to attempt to facilitate that effort through funding from the U.S. Department of Agriculture's Office of International Development and Cooperation.

RECOGNIZING THE GLOBAL CONCERN

In order for the boreal forest health data base concept to be accepted and implemented, a need must be recognized and clearly expressed. Previously, international attention was being directed to such aspects of forest health as acid deposition (Nordic Council of Ministries, 1988; Hall and Addison, 1991), radio-nucleoid and heavy metals contamination (Melnikov, 1991; Nordic Council of Ministries, 1992), and to the general international concerns for maintaining safe and healthy ecosystems. An additional international concern manifests itself in the potential problem of impacts on boreal forests from global climate change (USEPA, 1990). The importance of the boreal forest ecosystem in detecting climate change has been a point of considerable scientific interest (Kullman, 1990; Soloman, 1990).

Regionally, there are also concerns for forest health that are actually international in nature. In Finland, concerns for international deposition of heavy metals resulted in the research on gradient transect studies near Rovaniemi. Likewise, concern for global warming of an international nature was instrumental in establishing a series of growth chamber studies near Joensuu.

Likewise, regional concerns about acid rain in North America took on an international aspect along the border of the U. S. and Canada. This was one of the driving factors in the establishment of the U.S.'s National Atmospheric Precipitation Assessment Program (NAPAP) (Barnard et al, 1985). This resulted in studies in both the U. S. and Canada (Hall and Addison, 1991).

Inquiries into addressing such concerns often need to be dealt with at a global scale. Some of the more important concerns associated with boreal forests of today deal with features such as forest diversity, distribution, productivity, disturbance, and damage, to cite only a partial list. Degradation in boreal forest health can be manifested in changes in one or more of these areas of concerns.

> Some of the indicators to assess or measure for forest health change include the following:
>
> Visual Symptoms – Crown die-back, changes in crown density or transparency, increase in presence of pathogens or insects.
>
> Landscape Characterization – Changes in forest vegetation patterns.
>
> Growth Efficiency – Changes in radial growth or height growth in trees and shrubs.
>
> Foliar or Wood Nutrients – Changes in wood/foliar chemistry or nutrients.
>
> Soil Characteristics – Chemical, physical and nutrient content of soil.
>
> Bio-indicators – Ozone impact on highly sensitive vegetation.

Several years of research ensued in the eastern U.S. to speak to this as a National concern. One of the national U.S. legislative outgrowths of this concern was Forest Research and Atmospheric Research Act of 1988 which directed the Secretary of Agriculture "to increase the frequency of forest inventory in matters that relate to atmospheric pollution and conduct such studies as are necessary to monitor long-term trends in the health and productivity of domestic forest ecosystems."

This transitioned into the Forest Health Monitoring Program, a national program based on concerns for forest health in the U.S. This program is a joint effort by the U.S. Forest Service and the U.S. Environmental Protection Agency (EPA).

The implementation schedule for this was applied to those U.S. areas where forest health was of greatest concern, such as the eastern seaboard and in the west, California and

Colorado. Alaska, with its boreal forests, is currently on hold in this effort until monitoring plots have been implemented in the highly populated areas which have the most potential for forest health problems.

The EPA's grid system, with plots located about every 27 kilometers apart, will probably be de-intensified when applied to the boreal forests of Alaska. I suspect that in the remote areas of Alaska, the implementation grid will set plots at about 1/7 the intensity used in the contiguous 48 states. This would place the sites about 190 kilometers apart in Alaska, and result in about 600 monitoring sites, of which 200–300 will occur on boreal forest lands.

THE FINLAND/U.S. FOREST SERVICE BOREAL FOREST MONITORING AGREEMENT

In anticipation of the upcoming forest health monitoring program in Alaska, it was appealing to consider establishing a circumpolar forest health monitoring data base which could be used for exchanges of data and forest science around the northern hemisphere's forests. Since the government of Finland and the United States Department of Agriculture had signed an agreement for technical and scientific cooperation in 1988, this agreement could serve as a basis for further cooperation in the area of data collection and exchange in forest health monitoring data.

During the summer of 1991, using a grant from the U.S. Department of Agriculture's Office of International Development and Cooperation (OICD), Dr. Richard Werner, a U.S. Forest Service Entomologist working in Forest Health Monitoring in Alaska, and I traveled to Finland. We discussed this concept with Finnish Forest Research Colleagues.

To meet with a broad spectrum of forest and environmental scientists, we traveled throughout Finland, going as far north as Rovaniemi. During these travels and discussions, we began to come to a mutually agreeable direction for this process. A very long list of variables to be monitored was developed, along with suggestions for methods and sampling designs to capture the data. In overview, the following are only a few of the items that it was agreed that it was important to monitor:

In the area of monitoring for tree and stand changes, consider:
- vegetation composition, diversity and structure
- leaf area indices
- changes in tree crown density, transparency, and die-back
- wood and foliar chemistry
- changes in tree seed viability

In the area of general forest health, indicators to monitor include:
- foliar damage from ozone, acid rain or other atmospheric impacts
- increases in incidence of insect and disease on stem, limbs and foliage
- increases in incidence of root disease

In the area of tree mensurational, aspects to monitor include:
- radial growth rate
- periodic height growth
- mortality rates

In the area of soil science, characteristics to monitor include:
- Soil physics
- Soil chemistry and nutrients
- Soil biota –the total list of soils variables is 2 to 3 pages long.

There are also many ancillary data criteria to be recorded, such as:

- Climate
- Socio-economic factors
- Dendrocronological data
- Normalized differential vegetation indices from remote imagery

THE CIRCUMPOLAR BOREAL FOREST MONITORING CONCEPT

Efforts to develop this bi-lateral agreement for a common FHM data base between Finland and the U. S. in 1991 were quite encouraging. However, we anticipated that getting international approval for this concept from all of the boreal nations would be considerably more challenging.

In the fall of 1991, Dr. Richard Werner, of the U. S. Forest Service's Institute of Northern Forestry at Fairbanks, Alaska and I applied for, and were successful in obtaining, a $5,000 grant to initiate an international boreal forest health monitoring data base. During our current visit to Helsinki, Dr. Werner and I will attempt to close the OICD agreement between the U.S. and Finland. Following this meeting, we will travel on to Russia, Sweden, and Norway to continue the same process with those countries in an attempt to extend this to include all boreal countries in the boreal forest health monitoring data base effort.

It is recognized that lists of variables to monitor will generate much discussion and some significant differences of opinion as to what is important. The same is true when one discusses sampling systems and plot designs. There is no intention of imposing the U.S. FHM sampling system and plot design in the international boreal forest health monitoring program. It is only important to have statistically compatible, unbiased and robust sampling designs that are driven with compatible sampling techniques, collecting the same data in the same way, and supported by carefully detailed documentation.

CONCLUSION

The task of setting in place an international system for forest health monitoring of boreal forests is very ambitious, but attainable. It is very important to join in this effort in good faith with a minimum of personal and professional biases. If data are collected correctly and within consistent standards and guides and with well understood uses in mind, much can be accomplished in an effort such as this. Vitally important scientific data will result and be available for analysis in an international context.

By basing forest health monitoring decisions on well defined needs and well thought out results, there is promise of accomplishing goals that will be vital to sustaining the health of the boreal forests for the benefit of generations to come.

It behooves us to press forward in this endeavor, confident that this area of scientific cooperation will succeed.

REFERENCES

Barnard, J. E.; Bartuska, A. M.; Bradow, R. L.; Cowling, E. B.; Fege, A.; Hood, B.; Janetos, A.; Joyner, K.; Marx, D. H.; Pagano, T. A.; Preston, E. M.; Radloff, D.; Turner, R; Woodman, J. N. 1985: Science advisory board review of the forest effects research program. U.S. Environmental Protection Agency, Washington, D.C.

Hall, J. Peter and Addison, P. A. 1991: Responses to air pollution: ARNEWSassesses the health of Canada's forests. Can. For. Serv., Info. Rep. DPC-X-34, Ottawa, Ont., 42 pp.

Kullman, Leif. 1990: Climatic variability and the altitudinal margin of the boreal forest in Sweden. IN:

Proceedings for the Symposium on "Boreal Forests: State, Dynamics and Anthropogenic Influences." Archangelsk, Russia. p. 22–29.

Melnikov, S. A. 1991: Report on heavy metals. State of the Arctic Environment Reports. Arctic Centre, University of Lapland, Rovaniemi, Finland. p. 82–153.

Nordic Council of Ministries, 1990: General conclusions and recommendations. IN: Report from a Workshop on: "Effects of air pollutants and acidification in combination with climatic factors on forests, soils and waters of northern Fennoscandia." Copenhagen, Denmark. p. 7–10.

Nordic Council of Ministries, 1992: Atmospheric heavy metal deposition in northern Europe, 1990. Copenhagen, Denmark. 41 pp.

Solomon, Allen M. 1990: Use of the Taiga-tundra border for first detection of biospheric response to global environmental change. IN: Proceedings for the Symposium on "Boreal Forests: State, Dynamics and Anthropogenic Influences." Archangelsk, Russia. p. 40–42.

USEPA, 1990: Response and feedbacks of forest systems to global climate change.U. S. Environmental Protection Agency research Report. Corvallis, Oregon, USA. 156 pp.

TREE AND STAND MODELS IN FOREST INVENTORY

TREE AND STAND MODELS IN FOREST INVENTORY

Harold E. Burkhart
Department of Forestry
Virginia Polytechnic Institute and State University
Blacksburg, Virginia, U.S.A.

ABSTRACT

Forest management requires information on both current and future conditions. Forest inventories are taken at a given point in time; hence, inventory data must be updated. There are numerous alternatives for updating inventories. The use of tree and stand models for inventory updating is emphasized and the integration of inventory and growth and yield modelling is discussed. By more completely interfacing inventory and growth and yield modelling, information needed for forest management can be provided more efficiently.

Keywords: Growth, yield, inventory updating, modelling

INTRODUCTION

Managers need information on both current and future conditions in order to make prudent decisions. Forest inventories are taken only at one instant in time; however, forests are dynamic biological systems that are continuously changing. Because of the expense of obtaining inventory data, reinventories can be conducted only at infrequent intervals. Thus, the process of updating forest inventories–or projecting growth–is extremely important for effective management.

Updating of inventories is commonly accomplished through the application of growth and yield models. Many different approaches to modelling growth and yield have been taken. These approaches range from techniques which use individual trees as the basic projection unit to methods which use only overall stand summary data.

There has also been a great deal of effort devoted to the development of forest inventory techniques. However, to date, there has been relatively little attention focused on integrating inventory and growth projection.

The purpose of this paper is to consider methods for updating inventories and relationships between forest inventory and growth projection.

USES OF GROWTH AND YIELD MODELS

Forecasting growth and yield is implicit in the process of forest management. While growth and yield forecasts enter into virtually all decisions, the primary uses of growth and yield information can be categorized as follows: (i) inventory updating, (ii) evaluation of silvicultural alternatives, (iii) management planning, and (iv) harvest scheduling.

Growth and yield information is used for a variety of purposes; no single data base or modelling approach can be optimal for all purposes. As an example, if one were primarily interested in evaluation of silvicultural alternatives, designed-experiment type data with the relevant silivicultural treatments included would probably be used. The model structure would likely be quite detailed in terms of the structural equations and the types of output produced in order that the full range of treatments could be evaluated under varying assumptions. If, on the other hand, one were primarily interested in inventory updating, the data should be obtained from a representative sample of the types of stands to which the model is going to be applied. The input to the model would necessarily need to be consistent and compatible with the inventory data definitions and quantities available. The structural equations should be as simple and straightforward as possible for producing output (updated stand statistics) that is needed for and consistent with the inventory data base.

APPROACHES TO GROWTH AND YIELD ESTIMATION

Stand dynamics (i.e., the growth, mortality, reproduction, and associated changes in the stand) can be predicted through direct or indirect methods. Direct methods, such as the stand-table projection technique, involve field observations in existing stands. Past growth and mortality trends are used to infer future trends in the stands observed (additional detail is contained in Avery and Burkhart 1983 and Clutter *et al.* 1983.)

There are many situations in which direct observation of forest growth and mortality are not feasible, however. Diameter growth, mortality, and ingrowth relationships developed through stand-table projection techniques are not reliable for long periods of time. Furthermore, foresters often wish to evaluate a broad range of management alternatives. Inferences from past growth are limited to the conditions under which that growth occurred. Thus, when management actions are changing the characteristics of a forest, stand-table projection may not provide a realistic estimate of future growth.

Because of difficulties with using past growth to infer future growth of forests that are subjected to changing conditions, foresters have increasingly relied on indirect methods of predicting stand dynamics. That is, growth, mortality, and related quantities of a stand are inferred from the study of other stands through the application of growth and yield models. Inventories taken at one instant in time provide information on current volume. If appropriate variables for a growth model are measured as part of the inventory, then future growth can be predicted. The predictor variables for even-aged stands generally consist of age, site index, a measure of stand density (usually basal area or number of trees per unit area), and management treatments. Application of growth models is the preferred option for forecasting growth when management practices and changing conditions evolve the forest rapidly thus rendering measurement of past growth of limited value for estimating directly future growth.

A variety of approaches has been taken to growth and yield prediction. In American terminology, an "empirical yield equation" supposedly applies to "average" stocking. Because density is not explicitly included as a predictor variable, empirical yield functions apply only to the average density levels found on the sample plots used to estimate the parameters of the equation(s). Empirical yield functions have been fitted (e.g., Hahn and Stelman 1989, McClure and Knight 1984) and applied to inventory data bases as a tool for projecting the inventory. However, most growth and yield equations include density as a dynamic part of the stand projection system. Such models are commonly termed "variable-density" equations (or models).

Many investigators have used multiple regression techniques to predict growth and/or yield for the total stand or for some merchantable portion of the stand (such as Beck and Della-Bianca 1972, Bennett 1970, Burkhart and Sprinz 1984, Farrar 1979, Murphy and Beltz 1981, Sullivan and Clutter 1972). Stand level variables such as age, site index, basal area or number of trees per unit area are utilized in the whole stand approach to predict some specified aggregate stand volume. Volume distribution by size class is not provided.

A number of models have been developed which consider the stand in terms of the distribution of the number of trees per unit area by size-class. In most cases dbh classes have been used. A common modelling approach in this general category is a method based on a diameter distribution analysis procedure (for example, Bennett and Clutter 1968, Burkhart and Strub 1974, Dell *et al.* 1979, Schreuder *et al.* 1979, Smalley and Bailey 1974). The various diameter distribution models differ chiefly in the function used to describe the diameter distribution. In this approach, the number of trees per unit area in each diameter class is estimated through the use of a probability density function (pdf) which provides the relative frequency of trees by diameters. Mean total tree heights are predicted for trees of given diameters growing under given stand conditions. Volume per diameter class is calculated by substituting the predicted mean tree heights and the diameter class midpoints into tree volume equations. Yield estimates are obtained by summing the diameter classes of interest. Although only overall stand values (such as age, site index, and number of trees per unit area) are needed as input, detailed stand distributional information is obtainable as output.

Regardless of the probability density function used, the procedure involves estimating the pdf parameters for each plot in the data set (usually by the method of moments or maximum likelihood) and then developing regression equations to relate these parameter estimates to stand characteristics such as age, site index and number of trees per unit area. Unfortunately, functions for relating the pdf parameters to stand characteristics have not been fully satisfactory. Consequently an alternative method, sometimes called a "parameter recovery method," has been developed and applied. The parameter recovery method consists of forecasting overall stand attributes (such as average diameter, total basal area) and solving for the parameters of a theoretical diameter distribution model (such as the beta or Weibull) that will give rise to the overall stand attributes. Such an approach provides a direct mathematical link between the overall stand volume and the distribution of that volume. Additional information on parameter recovery methods can be found in the papers by Hyink and Moser (1983), Matney and Sullivan (1982), Cao *et al.* (1982) and Knoebel *et al.* (1986).

Approaches to predicting stand growth and yield which use individual trees as the basic unit are referred to as "individual-tree models." The components of tree growth in these models are commonly linked together through a computer program which simulates the growth of each tree and then aggregates these to provide estimates of stand growth and yield. Models based on individual-tree growth provide detailed information about stand dynamics and structure, including the distribution of stand volume by size classes.

Individual-tree models may be divided into two classes, distance independent and distance dependent, depending on whether or not individual tree locations are required tree attributes. Distance-independent models project tree growth either individually or by size classes, usually as a function of present size and stand level variables (e.g., age, site index, and basal area per unit area). It is not necessary to know individual tree locations when applying these models. Typically, distance-independent models consist of three basic components: (1) a diameter-growth component, (2) a height-growth component (or a height/diameter relationship to predict heights from dbh values), and (3) a mortality component. Examples of this approach include Belcher *et al.* (1982), Harrison *et al.* (1986), and Amateis *et al.* (1989).

Distance-dependent models vary in detail but are quite similar in overall concept and structure. Initial stand conditions are input or generated, and each tree is assigned a coordinate location. The growth of each tree is simulated as a function of its attributes, the site quality, and a measure of competition from neighbors. The competition index varies from model to model but in general is a function of the size of the subject tree and the size of and distance to competitors. Survival is controlled either stochastically or deterministically as a function of competition and/or individual-tree attributes. Yield estimates are obtained by summing the individual tree volumes and multiplying by appropriate expansion factors. Distance-dependent models include those of Newnham and Smith (1964), Ek and Monserud (1974), Hegyi (1974), and Burkhart *et al.* (1987).

USING GROWTH AND YIELD MODELS FOR INVENTORY UPDATING

In an overview of methods for updating forest inventories, Birdsey (1990) listed trend extrapolation, transition probability matrices, timber supply models, growth and yield models, sampling methods, remote sensing and geographic information systems, and combinations of these techniques as possible alternatives. The most appropriate approach will depend on the scope of the inventory, the information needed, and the data and updating tools available. In this paper I do not discuss or contrast various methods for updating inventories, but rather focus on the use of tree and stand models in forest inventory.

A major obstacle to applying growth models for inventory updating is the lack of compatibility between the inventory data and the growth model requirements. In many inventories only trees above a specified diameter class are measured, whereas typical growth models require information on all trees in the stand as input. Difficulties also arise due to missing data. For instance, site index may be required for the growth model but adequate field data for its estimation may not have been collected as part of the inventory. It is relatively easy to include appropriate measurements for applying growth models to the inventory data, but planning and integration is obviously needed.

Further incompatibilities between the inventory data base and the growth model occur when the growth model does not make use of all of the information available. In most inventories a stand table (number of trees by dbh class) is produced. If one applies a whole stand model, however, none of the information on the distribution of trees by diameter is used. Application of whole stand models causes additional difficulties because the estimates of current volume from the inventory plots and from the growth model will not be the same. (Various authors–such as Burk *et al.* 1981, Green and Strawderman 1986–have suggested methods for developing a composite estimate of current volume from inventory and growth model estimates.) Problems with incompatibilities between the inventory plot estimate of beginning volume and the beginning volume estimate of the growth model can be overcome by using a growth model that accepts the inventory-based tree list. The individual-tree volume estimating functions must, of course, be the same for the inventory and growth model computations. This compatibility of volume estimating functions further requires that the inventory field measurements of diameter, height and, for certain volume functions, form, be consistent with the tree characteristics projected in the growth model.

Alternative methods for applying a whole stand model to update plot volumes were evaluated by fitting the model of Sullivan and Clutter (1972) to data from the unthinned control plots of a growth study in loblolly pine (*Pinus taeda* L.) plantations. (The sampling and measurement procedures used in this study are described in Burkhart *et al.* 1987.) Using data from 93 plots resulted in the following parameter estimates:

$$\begin{aligned}\ln(Y_2) = {} & -1.940428 - 18.663720\ A_2^{-1} + 0.121460\ S \\ & + 1.616290\ (A_1/A_2)\ln(B_1) + 9.592798\ (1-A_1/A_2) \\ & -0.124625\ (1-A_1/A_2)S\end{aligned}$$

where Y_2 = volume (m^3/ha) for all trees 15 cm in dbh and larger to a 10 cm top diameter
A_2 = age at time 2
A_1 = age at time 1
B_1 = basal area (m^2/ha) at time 1
S = site index (m at base age 25 years)

The resultant equation was then applied to 60 plots which were not used in the fitting procedure. Initial volumes for the 60 plots were projected forward for 3, 6, and 9 years to correspond with the measurements taken. When estimating the future volume one can make a number of different assumptions. One logical approach is to assume the best estimate of future volume is that obtained from the yield projection function. This application implies that stands above or below the average volumes estimated by the yield model will approach the yield function in the future. This approach will be designated method 1. Another possible approach is to assume that the relative advantage or disadvantage exhibited by a stand now will apply to the future. Thus if the observed volume now is V_1 and the estimated current volume from the yield function is Y_1 then the ratio $R = V_1/P_1$ will apply to the future stand. That is, the yield function estimate for future volume Y_2, is adjusted as

$Y_2' = (R)(Y_2)$. This approach was designated method 2. There are, of course, numerous other assumptions that could be made but method 1 (stands progress towards the mean volume level for given levels of the whole stand predictor variables) and method 2 (any departure from the yield function will be maintained on a proportional basis) represent the ends of the continuum of interest.

Applying methods 1 and 2 to the 60 independent plots gave the following results:

	3–yr Projection		6–yr Projection		9–yr Projection	
	$\overline{Y-\hat{Y}}$	$\overline{\lvert Y-\hat{Y} \rvert}$	$\overline{Y-\hat{Y}}$	$\overline{\lvert Y-\hat{Y} \rvert}$	$\overline{Y-\hat{Y}}$	$\overline{\lvert Y-\hat{Y} \rvert}$
Method 1	16.6	27.6	1.9	31.0	–14.8	44.6
Method 2	–0.24	40.7	29.5	66.9	–62.5	99.7

where $\overline{Y-\hat{Y}}$ is the mean residual (bias)

$\overline{\lvert Y-\hat{Y} \rvert}$ is the mean of the absolute values of the residuals (all values are in m^3/ha).

Clearly, method 1 is more nearly unbiased for projections of 6 or 9 years and has a smaller mean for the absolute value of the residuals as well. Stands seem to approach the mean levels shown by the yield projection function fairly rapidly (i.e. within 6 years); method 1 performed much better than method 2 in the somewhat longer projection intervals. However, method 2 exhibited less bias for a short-term projection (3 years), which seems consistent with what one might expect. Some alternative that allows stands to approach the average as shown by the yield equation as a function of time interval may perform better than either of the methods tested here.

INTEGRATION OF FOREST INVENTORY AND GROWTH MODELS

Both inventories and growth and yield models are aimed at providing information for management decision making. Improved growth models for inventory updating can lengthen the time period between inventories, thus reducing costs. Data from forest inventories can be valuable for constructing yield equations (Walters *et al.* 1990). While temporary plot data are useful for volume over age functions, information from permanent plots is far more valuable from a growth and yield standpoint. Inventory data are also highly valuable for validating growth and yield models that were constructed from other data sources.

Growth and yield models are often constructed from regional sample data but they are applied to specific stands. Inventory data on the performance of specific stands can be used to adjust growth model predictions. Turnbull (1978) spoke of the need for feedback in growth and yield models "to adjust estimates due to fluctuations in operational treatment and conditions." Feedback should provide the capability to monitor the results of model projections, compare them with what is actually happening and make adjustments and corrections to subsequent projection cycles. Self-calibration procedures have been built into the stand prognosis model (Stage 1981), and Gertner (1984) has applied a sequential Bayesian procedure to localize a diameter increment model. Walters *et al.* (1991) developed a Kalman filter approach to localizing height-age equations. Their procedure employs the general concept of feedback by using information on a particular stand's height growth development to modify a regional site index equation. While methodology for using inventory data to modify growth and yield predictions has been explored, to date, operational applications of feedback have been limited.

Growth models can also be used to develop more efficient sampling designs. Data from the first Swiss National Forest Inventory is being used to develop a diameter distribution type model (Kaufmann 1990). This model will then serve as an aid in preliminary decision-making on changes in inventory design and the evaluation of any potential new procedures. The objective is to reduce the time and costs which pilot inventories involve by using computer simulations of stands to test methods for estimating standing volume and increment.

In conclusion, inventory and growth modelling activities must be integrated for maximum efficiency in providing information for forest management. The inventory design should allow for growth projection and construction of growth models, if needed. When applying growth models for inventory updating, one must insure that the sampling base on which the model is based is appropriate. By more completely interfacing inventory with growth and yield models, information needed for management can be provided more efficiently.

REFERENCES

Amateis, R.L., Burkhart, H.E., and Walsh, T.A., 1989: Diameter increment and survival equations for loblolly pine trees growing in thinned and unthinned plantations on cutover, site-prepared lands. *Southern Journal of Applied Forestry*, vol. 13, no. 4, pp. 170–174.

Avery, T.E., and Burkhart, H.E., 1983: *Forest Measurements*. 3rd Ed. McGraw-Hill, New York, NY, 331 pp.

Beck, D.E., and Della-Bianca, L., 1972: Growth and yield of thinned yellow-poplar. U.S. Forest Service, Research Paper SE-101, 20 pp.

Belcher,D.W., Holdaway, M.R., and Brand, G.J., 1982: A description of STEMS–the stand and tree evaluation and modeling system. U.S. Forest Service, General Technical Report NC–79, 18 pp.

Bennett, F.A., 1970: Variable-density yield tables for managed stands of natural slash pine. U.S. Forest Service, Research Note SE-141, 7 pp.

Bennett, F.A., and Clutter, J.L., 1968: Multiple-product yield estimates for unthinned slash pine plantations–pulpwood, sawtimber, gum. U.S. Forest Service, Research Paper SE-35, 21 pp.

Birdsey, R., 1990: Updating methods for forest inventories–an overview. In State-of-the-Art Methodology of Forest Inventory: A Symposium Proceedings (Ed. V.J. LaBau and T. Cunia). U.S. Forest Service, General Technical Report PNW-GTR-263, pp. 429–435.

Burk, T.E., Hansen, M.H., and Ek, A.R., 1981: Combining sources of information for improved in-place inventory statistics. In In-place resource inventories: principles and practices. Proceedings of a National Workshop. (Ed. T.B. Brann, L.O. House IV, and H.G. Lund). Society of American Foresters Publication no. 82–02, pp. 413–420.

Burkhart, H.E., Farrar, K.D., Amateis, R. L., and Daniels, R.F., 1987: Simulation of individual tree growth and stand development in loblolly pine plantations on cutover, site-prepared areas. School of Forestry and Wildlife Resources, Virginia Polytechnic Institute and State University, Publ. FWS-1–87, 47 pp.

Burkhart, H.E., and Sprinz, P.T., 1984: Compatible cubic volume and basal area projection equations for thinned old-field loblolly pine plantations. *Forest Science*, vol. 30, no. 1, pp. 86–93.

Burkhart, H.E., and Strub, M.R., 1974: A model for simulation of planted loblolly pine stands. In Growth Models for Tree and Stand Simulation (Ed. J. Fries). Royal College of Forestry, Stockholm, Sweden, pp. 128–135.

Cao, Q.V., Burkhart, H.E., and Lemin, R.C., 1982: Diameter distributions and yields of thinned loblolly pine plantations. School of Forestry and Wildlife Resources, Virginia Polytechnic Institute and State University, Publ. FWS-1–82, 62 pp.

Clutter, J.L., Fortson, J.C., Pienaar, L.V., Brister, G.H., and Bailey, R.L., 1983: *Timber Management: A Quantitative Approach* John Wiley & Sons, New York, NY, 333 pp.

Dell, T.R., Feduccia, D.P., Campbell, T.E., Mann, W.F., and Polmer, B.H., 1979: Yields of unthinned slash pine plantations on cutover sites in the West Gulf Region. U.S. Forest Service, Research Paper SO-147, 84 pp.

Ek, A.R., and Monserud, R.A., 1974: FOREST: A computer model for simulating the growth and reproduction of mixed species forest stands. University of Wisconsin School of Natural Resources, Research Report R2635, 13 pp.

Farrar, R.M., 1979: Growth and yield predictions for thinned stands of even-aged natural longleaf pine. U.S. Forest Service, Research Paper SO-156, 78 pp.

Gertner, G.Z., 1984: Localizing a diameter increment model with a sequential Bayesian procedure. *Forest Science* vol. 30, no. 4, pp. 851–864.

Green, E.J., and Strawderman, W.E., 1986: Reducing sample size through the use of a composite estimator: an application to timber volume estimation. *Canadian Journal of Forestry Research*, vol. 16, no. 5, pp. 1116–1118.

Hahn, J.T., and Stelman, J.M., 1989: Empirical yield tables for Wisconsin. U.S. Forest Service, General Technical Report NC-131, 46 pp.

Harrison, W.C., Burk, T.E., and Beck, D.E., 1986: Individual tree basal area increment and total height equations for Appalachian mixed hardwoods after thinning. *Southern Journal of Applied Forestry*, vol. 10, no. 2, pp. 99–104.

Hegyi, F., 1974: A simulation model for managing jack-pine stands. In Growth Models for Tree and Stand Simulation. (Ed. J. Fries). Royal College of Forestry, Stockholm, Sweden, pp. 74–90.

Hyink, D.M., and Moser, J.W., Jr., 1983: A generalized framework for projecting forest yield and stand structure using diameter distributions. *Forest Science*, vol. 29, no. 1, pp. 85–95.

Kaufmann, E., 1990: Modelling with data of the first Swiss National Forest Inventory. In State-of-the-Art Methodology of Forest Inventory: A Symposium Proceedings (Ed. V.J. LaBau and T. Cunia). U.S. Forest Service, General Technical Report PNW-GTR-263, pp. 420–427.

Knoebel, B.R., Burkhart, H.E., and Beck, D.E., 1986: A growth and yield model for thinned stands of yellow-poplar. *Forest Science* Monograph 27, 62 pp.

Matney, T.G., and Sullivan, A.D., 1982: Compatible stand and stock tables for thinned and unthinned loblolly pine stands. *Forest Science*, vol. 28, no. , pp. 161–171.

McClure, J.P., and Knight, H.A., 1984: Empirical yields of timber and forest biomass in the Southeast. U.S. Forest Service, Research Paper SE-245, 75 pp.

Murphy, P.A., and Beltz, R.C., 1981: Growth and yield of shortleaf pine in the West Gulf region. U.S. Forest Service, Research Paper SO-169, 15 pp.

Newnham, R.M., and Smith, J.H.G., 1964: Development and testing of stand models for Douglas-fir and lodgepole pine. *Forestry Chronicle*, vol. 40, pp. 492–502.

Schreuder, H.T., Hafley, W.L., and Bennett, F.A., 1979: Yield prediction for unthinned natural slash pine stands. *Forest Science*, vol. 25, no. 1, pp. 25–30.

Smalley, G.W., and Bailey, R.L., 1974: Yield tables and stand structure for loblolly pine plantations in Tennessee, Alabama, and Georgia Highlands. U.S. Forest Service, Research Paper SO-96, 81 pp.

Stage, A. R., 1981: Use of self-calibrating procedures to adjust general regional yield models to local conditions. In Proceedings XVII IUFRO World Congress, Kyoto, Japan, pp. 365–375.

Sullivan, A.D., and Clutter, J.L., 1972: A simultaneous growth and yield model for loblolly pine. *Forest Science*, vol. 18, no. 1, pp. 76–86.

Turnbull, K.J., 1978: Long-term yield forecasting models: validations and iterative estimation. In Growth Models for Long Term Forecasting of Timber Yields. (Ed. J. Fries, H. E. Burkhart, and T. A. Max). School of Forestry and Wildlife Resources, Virginia Polytechnic Institute and State University, Publ. FWS-1–78, pp. 224–229.

Walters, D.K., Burkhart, H.E., Reynolds, M.R., Jr., and Gregoire, T.G. 1991: A Kalman filter approach to localizing height-age equations. *Forest Science*, vol. 37, no. 6, pp. 1526–1537.

Walters, D.K., Ek, A.R., and Czysz, D., 1990: Construction of variable-density empirical yield equations from forest management inventory data. *Northern Journal of Applied Forestry*, vol. 7, no. 3, pp. 110–113.

ASSESSING STEM QUALITIES AND USING DYNAMIC PROGRAMMING TO PREDICT LOG-PRODUCT VOLUMES IN INVENTORY

C.J. Goulding, M.W. Deadman, M.E. Lawrence
Forest Research Institute
Rotorua, New Zealand

ABSTRACT

The merchantable volumes of log-products in a stand of trees depend both on the trees themselves and on the way they are bucked (cross-cut) into logs. This paper describes a method which first assesses standing trees in an inventory sample in the forest, then simulates the bucking of the stems using dynamic programming to estimate the yield of log-products. The inventory system has been in widespread use in New Zealand over the last 16 years, and has recently been upgraded. The results from these inventories are used operationally for marketing and logging planning. When combined with yield predictions obtained from growth models, they contribute to the woodflow predictions derived from a nation-wide description of the plantation forests.

Keywords: National Inventory, volume assessment, tree description, dynamic programming

INTRODUCTION

The 1.28 million hectares of forest plantations in New Zealand supply the total domestic wood market and an expanding export trade (Neumann 1992). The species used are exotic to New Zealand and comprise mainly Radiata pine, *P. radiata* D.Don (89%), and Douglas fir, *Pseudotsuga menziesii* (Mirb.) Franco (6%), along with minor areas of Eucalypts and other pines. The area of plantations has tripled since 1965, and with the short rotations of 30 years practised for the new radiata pine plantations, the harvest is expected to increase 40% over the current level of 13.5 million m^3 per year by the year 2005 (Edgar, Lee and Quinn 1992).

Forest sector strategy and development studies depend on accurate and comprehensive resource information. Afforestation in New Zealand occurred in two main periods, in the 1920's and 1930's, and again from the mid 1960's to the late 1980's. The consequent imbalance of the age class distribution, coupled with the realization that plantation forestry was highly profitable, caused a tight timber supply relative to demand over an extended period, requiring precise yield regulation. The upsurge in production now offers many investment opportunities in processing facilities, but also increases the necessity for reliable resource information.

The forests are managed as even-aged planted stands with well defined boundaries. Mapping is accurate, and silvicultural records by and large well kept, even for the smaller owners. The stands are continuously inventoried throughout their life with silvicultural work assessments, quality control procedures and mid-rotation and pre-harvest inventories. The mid-rotation and pre-harvest inventories provide operational data to the owners for marketing and logging management, and also provide the bulk of the data that ensure that yield tables derived from growth models are indeed accurate. The results are used for prospecting markets, negotiating log sales, scheduling harvesting and planning logging operations. Inventory coverage is stand-based and intensive. For example, one large company carries out two pre-harvest inventories for all stands, five years and again one year before the time of harvesting, with about one inventory plot at each occasion for every five hectares.

One method is used virtually throughout New Zealand. This is the Method for the Assessment of Recoverable Volume by Log-types (MARVL), originally implemented on main frame and mini-computers (Deadman and Goulding, 1979) and modified and upgraded as MicroMARVL, implemented on IBM compatible personal computers (Deadman, 1990). The operational application of the method to optimize profitability at harvest time is described by Goulding (1992). This paper describes the MicroMARVL system, as implemented in New Zealand, concentrating on the methods used to describe a tree and to predict log product volumes. Use of the information collected in operational inventories for a national inventory of plantation forests is described briefly.

THE INVENTORY SYSTEM

The merchantable volumes of log-products that can be obtained from a stand at time of harvest depend both on the characteristics of the trees within the stand and the decision making when cross-cutting (bucking) the stem into logs. Stands of trees can yield a wide range of product percentages depending on the differing specifications of logs that could potentially be cut, on market demands and on the relative values of the logs. It is incorrect to assume that the percentage composition of log-products in the total volume of a stand is fixed (Twaddle and Goulding 1989).

The inventory system has two distinct phases; the field work to collect the data, and subsequent analysis using computer programs. In the field assessment, temporary sample plots are located in the forest, as in any inventory procedure. The trees sampled are measured and objectively assessed for quality or grade changes up the stem. This assessment is independent of the specifications for the log-making procedure.

The computer analysis program predicts the yield of logs as a function of a set of log-product types with their definitions in terms of size, permissable grades and relative values. It first models the breakage, volumes, taper and grades of the tree stems in the field data. Then it simulates the felling of the stem and mimics the cross-cutting by optimizing the total value of the logs obtained from each stem using a dynamic programming routine and the set of log-product types supplied at the time of the analysis. The inventory field data can be reanalysed many times with differing sets of log-product definitions.

In order to provide maximum flexibility when using the system, the stem qualities or grades that are to be recognized in the forest are defined by the user for each inventory, prior to the field work. As far as possible, the grades should be independent of specific log-products, and are defined in terms which describe the fundamental properties of a stem that affect its subsequent inclusion in a log-product. The definition of the grades should not include merchantable small end diameter or length limitations, for example, "greater than 25 cm inside bark", but should be defined in terms of characteristics such as branch size or stem defects. Each grade is given a single, unique alphabetic code.

THE TREE DESCRIPTION

The method of describing a tree in the forest must provide for differing operational needs, must follow consistent, logical rules, and must be as independent as possible of the analysis to predict the yield of merchantable logs. This section describes the principles and methods used to describe the tree, defining precisely the rules and notation employed. The tree description method could be used with any inventory or sample plot analysis routine.

The field procedure is to sample trees from the population being inventoried, using some form of plots and sampling procedure. Each tree included in the sample that is to be measured is first measured for diameter at breast height (dbh) and then "cruised " to assess the type and lengths of the wood qualities along the stem. The tree stem is mentally divided into one or more segments of varying lengths, within each of which the stem is considered to be of uniform grade. Starting at the base of the tree, the grade of the stem is assessed in the first segment, and the height to the next change in grade estimated. The next segment is assessed in the same way until the tip of the tree is reached. The data for a uni-leadered tree with no structural defects is recorded as

treeno dbh grade1 height1 grade2 height2 grade3...etc.

where

treeno is the tree identification number
dbh is the diameter at breast height measured in mm
grade1, grade2, grade3 are alphabetic codes representing the grades
height1, height2 are the heights above ground of the changes in stem grade.

Note. In New Zealand breast height is defined as 1.4 m above ground level.

The last item on a line can be either an alphabetic code denoting a grade, in which case an estimate is made by the computer program of the height of the tree from a height/dbh relationship, or a height denoting the total height of the tree obtained by direct measurement. The simplest case is where the tree stem is of a uniform quality, and is not measured for height, tree number 1 below. The stem of tree number 2 has four segments of differing quality before 9.2 m, after which the stem is considered to be entirely of grade "C" to its tip, the height of which is not measured but will be estimated from the local height /dbh relationship based on the diameter at breast height above the ground. The height of tree 3 is measured as 24.6 m.

1 351 A

2 328 A 5.5 B 6.1 C 8.2 B 9.2 C

3 304 C 10.4 B 24.6

When assessing grades no attention (within reason) is paid to merchantable lengths or diameters. The length of stem of quality B in tree 2 between 5.5 m and 6.1 m is only 0.6 m., hardly enough to make a log. Nor is consideration made as to whether the diameter of the stem is large enough to make a log of a certain type. Log making, or bucking, must be separated from the field assessment if flexibility in subsequent analysis is to be preserved. However, in practice, there is little point in assessing every small segment of high grade within segments of low grade if the lengths are obviously too small to ever make a merchantable log.

To model the shape of the stem, the diameters inside bark at intervals along the stem are predicted by the computer program using a taper model (Goulding and Murray, 1976, and Gordon, 1983) with the diameter at breast height and leader height as independent variables. A severe reduction in the diameter of the stem can occur in some trees, invalidating stem diameters predicted from the taper model. The height of such a change in stem taper is estimated or measured in the field and recorded on the forms with the taper reduction denoted by a ">" symbol. The diameter of the stem at a nominal breast height above the point where such a reduction occurs is then estimated or measured and recorded immediately following the ">" symbol. The taper model in the computer program predicts subsequent diameters based on a subtree with this dbh and a total height equivalent to the remaining length of the stem. Tree 4 has its total height estimated from the height/dbh relationship and stem diameters estimated from the taper model for a tree with this height and dbh of 460 mm up to 7.6 m along the stem. At 7.6 m the stem has a sharp reduction in diameter, and at the nominal breast height above 7.6 m (ie at 7.6 + 1.4 = 9.0 m, in New Zealand) the diameter is estimated as 250 mm. The diameters of the stem above 7.6 m are estimated by the taper model in the computer program using 250 mm as the dbh, and a total tree height derived from the original estimate of height less 7.6 m.

```
4  460 A 4.5    B 7.6 > 250  C
```

Some trees have structural damage to the stem, for example broken or dead tops. The stem is cruised in the usual way up to the damage. Then the height above ground of the damage is recorded and an "*" symbol used, as at 6.1 m in tree 5. A mandatory cross-cut in the stem is denoted by a "%" symbol immediately above a recorded height, as at 8 m in tree 6.

```
5  302   A 5.5    B 6.1 *

6  350   A 8 %   B
```

Other trees have the stem forking into more than one leader, requiring a cross-cut to be made, or have merchantable side branches which require a chamfer cut. To define the structure of a multi-leadered tree each leader is recorded on a separate line. The height at which leaders would be cross-cut at a fork is assessed and the "<" symbol used to denote the fork. Each subsequent leader is considered as a "subtree", and the diameter at the nominal breast height above the cut assessed. Each leader is then assessed in the same way above the fork as the main stem, with multiple grades if necessary. Tree 7 has a stem of quality A grade up to 6 m, where it forks into two leaders each of quality C. The diameter of the stems of each leader is assessed as 250 mm and 220 mm at the nominal breast height above the cut, (6 + 1.4 = 7.4 m, in New Zealand). Forking simultaneously into two or more leaders is recorded similarly, e.g. using a third line, as in tree 8.

```
7  401 A 6   <  250   C
             <  220   C

8  438 A 6   <  250   C
             <  220   C
             <  190   B
```

The indentation of the recording of the forks adds clarity to the field description. A picture of the tree lying on its side with the base to the left and the tops to the right can easily be imagined.

If another fork occurs at a higher level than the first, then it is recorded by another "<" symbol.

```
9  489   B 6   <  350   W 6.5   C 9   <     150    P
                                      <<    160    P
               <  320   W 6.5   B
```

The double "<<" symbols on the second line indicate which level of forking this particular leader belongs with, here at 9 m, whilst the third line is a leader from the fork at 6 m. The rule is that the number of "<" symbols at the start of each line for a new leader must be the same as the number of "<" symbols at and below that level of the forking. Tree 10 has six leaders with three levels of forking.

```
10   542  B 3  < 405    P 6  < 310  C     12     <     150   P
                                                 <<<   140   P
                             <<250  C
               < 450    C 7  < 320  P
                             <<250  C     14     <     160   P
                                                 <<<   140   C
```

The rule of starting each line with the required number of "<" symbols would not be necessary if indentation of the recording were strictly adhered to. However, in the MicroMARVL implementation, free format of data is permitted to simplify data entry, and this rule is mandatory. It has the benefit of reducing the likelihood of subsequent misinterpretation if field parties have been careless in lining up their writing on field forms.

Trees 7, 8, 9 and 10 are depicted as having each of their leaders reaching the same height which would be estimated from their dbh's of 401, 438, 489 and 542 mm respectively. Differing heights of leaders can be measured and recorded by terminating each line as appropriate with the measured height. Similarly, several stem grades can be recorded for each leader, as well as dead tops or forced cuts. Tree 11 has the first leader with grades C and B and a height estimated from the height / dbh relationship based on a tree of 450 mm dbh; the second leader of grade W from the fork to 6.5 m then grade P to its tip at 15 m height; and the third leader of grade P to a broken top at 10 m.

```
11   450  A 3.5   B 6    < 320  C 12        B
                         < 250  W 6.5       P      15
                         < 220  P  10 *
```

Each segment above a fork is thought of as a subtree, and its stem diameters and taper estimated from the taper model with the appropriate values for dbh and tree height used as independent variables.

Merchantable branches differ from leaders arising from a fork in that they are cut from their main stem by a chamfer cut, not a cross cut. This cut may not necessarily affect the quality of the main stem, especially in low grade material. A branch is therefore described with the same notation and recorded on a separate line as with any other leader, but is preceded by a "+" symbol. Branches should be described after all other leaders emanating from forks. It is not mandatory to record their effect on the main stem. Usually the description of the branch is completed by specifying the length of the branch, but if omitted, an estimate is made by the computer program using the height/dbh relationship. Tree 12 has a merchantable branch arising from the main leader, of 155 mm diameter at 1.4 m from its base and with length 10 m.

```
12   320  B 4  P 5  B
            + 15    P     10
```

THE ANALYSIS PROGRAM

The basis of the analysis method is the optimal bucking algorithm of Pnevmaticos and Mann (1972). The data from each tree measured and cruised for grade is used to build a model of the tree stem. A local height / dbh relationship is derived from those trees that have been measured for height and is used to predict total height for the others, with the point at which a stem breaks on felling being predicted by a breakage model. Each leader is divided into short intervals, typically 0.1 to 0.3 m long. For each interval, the general taper and volume equations are used to predict the end diameters inside bark and the volume, with the grade known from the field data. The algorithm is then applied to each leader to predict that log-product yield which maximizes the gross value of the leader.

In the MicroMARVL implementation, preprocessing of the list of potential log types and their specifications is carried out to speed up the optimization routine. Similarly, the implementation of the algorithm has been enhanced considerably with numerous logical rules to avoid wasteful computation. The implementation is a full implementation, in that pieces of waste as short as one interval may be cut from the stem at any point, and all possible log lengths of any multiple of the interval length may be cut within the limits allowed by the log definitions (both fixed length and random length logs can be catered for). Some consideration was given to using the algorithm proposed by Danielsson (1985), which under Swedish conditions is extremely fast, but the New Zealand requirement that short pieces of merchantable material be permitted to be downgraded to waste, particularly at the butt, precluded any advantage from this method over careful coding of the Pnevmaticos and Mann algorithm.

In practice, the list of possible log-products may have six to ten types of log-products, each with a fixed length or a range of lengths (either multiples of a length e.g. 0.3 m, or true random lengths e.g. between 3.5 – 6.1 m). Often, tree stem segments may be 40 m long, and there can be as many as 1,000 trees in a large stratified random inventory. On a "386" type personal computer, processing time for such an inventory is now a few minutes.

MicroMARVL is written in "C", with the suite of programs menu driven. A variety of sampling schemes is catered for; simple random, stratified random and double sampling. Plot types include bounded plots, point or angle (Bitterlich) plots and horizontal line sampling. Routines to project the inventory data forward a few years in time are also available, thus the inventory need not be conducted in the exact year the information is required. Inventory data collected for marketing purposes is saved and reanalysed in conjunction with additional inventory data collected several years later and used for operational logging planning. In addition to the main analysis program, there is a program which checks the consistency of the rules for defining the structure of the tree, as well as likely errors in the measurements and cruising. File maintenance facilities are present to create, maintain and report on the different sets of quality code and log-product type definitions. A program written in Pascal for field data-entry computers is also available, to allow immediate, on-site data checking.

The assumption that cross-cutting the stem to obtain maximum value mimics what is happening in the forest is not always true. Differences between inventory predictions and logging results encouraged the development and use of a separate computer system to audit log-making practises (Geerts and Twaddle, 1984, Twaddle and Goulding, 1989).

NATIONAL PLANTATION FOREST INVENTORY

In New Zealand, the data collected by the operational inventories contributes indirectly to a national inventory of plantation forests, the National Exotic Forest Description (NEFD). The NEFD report provides a summary of plantation areas on an annual basis (Neumann 1992), with the 1991 report being the eighth in the series. Its coverage is restricted solely to forests managed for production. The area and associated yield table data bases are maintained by the Ministry of Forestry. Direction for the development of the NEFD databases and policies regarding the handling of the data is provided by the NEFD steering committee comprising representatives nominated by the New Zealand Forest Owners Association and the Ministry of Forestry. Periodically, the committee commissions a study to predict future national woodflows. The last of these was in 1986 (Burrows et al. 1987), and the next is in the final stages of analysis (at August, 1992).

The NEFD is based on data supplied voluntarily by forest owners. Four companies own 62% of the plantations, with a further 12% being owned by five more companies. The 1991 survey of all owners with more than 100 hectares resulted in area/ age/ silvicultural regime data being directly captured from an estimated 91% of the total plantation resource. The remaining areas are estimated from a variety of sources, chiefly the 1990 Agricultural

Census which, however, lacks the detail of the NEFD direct survey. Log-product yield data are obtained directly from the larger companies only. They are derived by using growth models and are modified by experience factors obtained from inventory and harvesting uplift records. Because of the intensity of exotic forest management, the forest resource information held by the companies is thought to be accurate. Thus the predictions of yields supplied to the NEFD are derived from and checked against a large amount of measurement data by the forest owners themselves.

The intensity of inventory obtained by using MARVL thus improves the quality of yield data for the NEFD. The concentration of ownership of the resource justifies reliance on the accuracy of voluntary contributions of area and yield data to the Ministry of Forestry. A consensus view on accuracy of yield tables is important and it would be difficult to reach this consensus without the widespread use of a common, reliable inventory method. The NEFD does not need a large scale measurement effort at infrequent intervals, because the forest managers routinely inventory their forests. This reduces the costs of data collection and processing, eliminates errors caused by sampling and allows the area description to be updated on an annual basis.

CONCLUSIONS

The MicroMARVL system employs user-defined quality codes or stem grades, and a formal, precise notation for describing the stem of a tree, which gives great flexibility to the field procedures. Separating the description of the tree in the forest from its subsequent analysis in the office allows the inventory officer to reanalyse the data from an assessment, varying the log-product specifications to determine the sensitivity of predictions of the likely yield of log-products to changes in those specifications. Using a dynamic programming algorithm chooses the optimum bucking pattern for each tree, and the results focus managers on maximizing value, rather than volume productivity. The inventory system is a decision support tool for forest management, rather than a purely passive predictive method.

Benefits from using the results outweigh the costs of carrying out detailed and timely "in-place" inventory. The flexibility of the system and its successful implementation on personal computers has greatly increased the amount of preharvest inventory carried out in New Zealand's plantations over the last decade, and has enhanced the quality of yield data required for the National Plantation Forest Inventory. There is no reason why the system cannot be extended to other conditions, and it has been used in the tropical hardwood mahogany plantations of the Fiji Department of Forestry, for example.

REFERENCES

Burrows, G.D., Levack, H.H., Novis, J.B. 1987: A national forestry planning model for NewZealand. Pp in 231 – 254 in Roche, M.M. and Hodder, R. (eds.) Proceedings of 56th ANZAAS Conference "Social and economic perspectives on forestry and agroforestry", Massey University, Palmerston North. January 1987.

Danielsson, B. 1985: Datorstodd aptering for praktisk tillampning. (Computer aided scaling – a practical implementation). Doctoral thesis, Sveriges Lantbruksuniversitet, Garpenberg.

Deadman, M.W. 1990: MicroMARVL preharvest inventory – User guide. Forest Research Institute Software Series No 7, Rotorua.

Deadman, M.W.and Goulding, C.J. 1979: A method for the assessment of recoverable volume by log types. *New Zealand Journal of Forest Science* 9(2) : 225–239.

Edgar, M.J., Lee, D. and Quinn, B.P. 1992: New Zealand forest industries strategy study. NewZealand Forest Industries Council, Wellington. 278 pp.

Geerts, J.M.P. and Twaddle, A.A. 1984: A method to assess log value loss caused by cross-cuttingpractice on the skidsite. *New Zealand Journal of Forestry* 29(2): 173–184.

Gordon, A. 1983: Comparison of polynomial taper equations. *New Zealand Journal of Forestry*

Science. *13*(2): 146–155.

Goulding, C.J. 1992: Preharvest assessment systems for optimizing profitability. Paper presented ata IUFRO S3.05/06 workshop "Computer supported planning of roads and harvesting". August 1992, Munich

Goulding, C.J. and Murray, J.C. 1976: Polynomial equations that are compatible with existing volume equations. *New Zealand Journal of Forest Science*. *5*(3): 313–322.

Neumann, A. 1992: A national exotic forest description as at 1 April 1991. Edition 8. Ministry of Forestry, Wellington.

Pnevmaticos, S.M. and Mann, S.H. 1972: Dynamic programming in tree bucking. *Forest Products Journal* *22*(2): 26–30.

Twaddle, A.A. and Goulding, C.J. Improving profitability by optimising log-making. *New Zealand Journal of Forestry*. *34*(1): 17–23.

THE EMPIRICAL BASIS FOR TREE AND STAND MODELLING IN FINLAND

Kari Mielikäinen & Hans Gustav Gustavsen
Professor and Senior Researcher
Department of Forest Production
The Finnish Forest Research Institute
Finland

ABSTRACT

The principal aim of this paper is to give a general view of the empirical material available for developing tree and stand models in Finland. Broad empirical material measured mainly on permanent plots forms the necessary basis for theoretical modelling and it also ensures the practical application of the models developed. The permanent plots used can be classified into two categories:

The first category comprises about 5000 single permanent plots connected to the National Forest Inventory tracts (NFI 6 and 7) and about 3000 plots in a separate systematical tract system. The plots were established in forest stands both on mineral soils and peatlands in the period 1976–1988, and they have been remeasured once or twice by now.

Another category contains permanent plots in subjectively selected experimental stands. These 600 experiments consist of 10000 single plots and 150000 remeasured sample trees. The plots have been measured and treated several times over a period of almost 70 years by the Finnish Forest Research Institute.

In addition to the net work of permanent plots, single tree and stand information have been recorded in the course of eight National Forest Inventories using temporary plots. In conclusion, our empirical material is comprehensive and in the future more effort must be given to the theoretical aspects of tree and stand modelling on the basis of this material.

Keywords: Modelling, National Forest Inventory, permanent plots

INTRODUCTION

Tree and stand modelling aims at describing reality in a mathematical way. Growth models are made for predicting stand development or explaining the effect of single predictors on it. The predictions needed in forest management must be at the right level both regionally and over a long-term time horizon. The latter demand is difficult to fulfill. The ongoing environmental change makes long-term predicting of stand development unreliable when using growth models based only on past growth.

More than 300 stand and individual tree models or model groups for predicting tree and stand characteristics and their development have been published in Finland in the period 1929–1990 (Mäkelä & Salminen 1991). From the very beginning modelling techniques have developed from tabular an graphical smoothing of measured material to more sophisticated regression and process models. The empirical material beyond these models has in most cases consisted of temporarily measured tree and stand plot data. Temporary sample plots located systematically over the whole country in eight National Forest Inventories have produced valuable data for model development and testing.

In addition to temporary measurements, permanent study plots have also been established in experimental stands already since the early 1920s by the Finnish Forest Research Institute. The oldest experiments were established by Yrjö Ilvessalo (Ilvessalo 1932). In spite of the long sequence of remeasurements and treatments over a long period, permanent data and especially the so-called old experiments have not been utilized very intensively in tree and stand modelling.

The principal aim of this paper is to give a general view of the broad empirical material available on permanent study plots in Finland. Some aspects connected to the utilization of the data for tree and stand modeling are pointed out. The paper deals with two categories of permanent plots and data from felled trees for stem analysis as the third category:

1. Permanent plots in subjectively selected experimental stands.
2. Permanent plots of Natinal Forest Inventories (NFI .
3. Felled sample trees in the NFI7 and NFI8 sample plots.

PERMANENT PLOTS IN EXPERIMENTAL STANDS

Temporary or permanent plots measured in objective inventories are best suited for models predicting the development of trees or stands in a certain area and under certain silvicultural treatments. The only way to get information concerning new methods of stand treatments is to establish experiments. The treatments applied can be thinning intensity, way of thinning, fertilization, pruning, ditching of peatlands etc. In 1985, the Department of Inventory and Yield of the Finnish Forest Research Institute had about 600 on-going experiments (9500 single plots). Some of the most comprehensive experimental series are shown in Fig. 1. Still more similar experiments have been established for studies dealing with peatland forests, special silvicultural problems and forest genetics.

The most common statistical design in the experiments for growth and yield studies in Finland has been the randomized block system, where the untreated plot is used as control. The size of a single plot is generally 0,1 hectares and the number of tallied trees 100–200. The tallied trees are numbered, measured for dbh and usually mapped out in a coordinate system. This makes the data suitable for constructing distance-dependent single tree growth models. Some other characteristics concerning crown dimensions, vitality and technical quality are usually estimated for all trees on the plot, too.

About 30 objectively selected sample trees on each plot are measured for height and tapering. In many experiments tapering is determined by measuring diameters at several relative heights.

PERMANENT PLOTS IN NATIONAL FOREST INVENTORIES (NFI)

The broadest empirical material in this category is provided by the NFI8 permanent plots, established in stands on forest, scrub and waste land in 1985–1986 (Fig. 2 a). By now, they have been remeasured once in 1990–1991. The principal aim of these inventory plots is to obtain continuous information about the changes taking place in Finnish forests. These changes can be caused, for example, by cuttings, different forms of damage or simply by tree growth. The plots are as inconspicious as possible in order to guarantee neutrality with regard to results concerning silvicultural activities in practical forestry.

The NFI8 permanent plots form a cluster of 3–4 plots in a systematic sample tract system. The distance between plots is 200 metres in the south of the country and 600 metres in the north. The distance between tracts is in southern Finland 16 kilometres and in northern Finland 32 (east-west) or 24 kilometres (south-north).

The size of a single circular plot varies from 100 m^2 to 300 m^2 depending on the average dbh of the stand. All tallied trees greater than 4,5 cm dbh are mapped out and classifications concerning vitality, technical quality etc. are done. Height, taper and length of green crown will be measured from the sample trees selected near the plot centre.

The second permanent plot network connected with NFI6 or NFI7 tracts (Kuusela 1978) is that of INKA (Inventory Growth Plots), TINKA (Young Forest Inventory Growth Plots), SINKA (Peatland Forest Inventory Growth Plots) and SUOJAINKA (Protection Forest Inventory Growth Plots) (see Figs. 2 b-e). The INKA plots were established in 1976–1982 and they have been remeasured twice in 1981–1987 and 1986–1992. The TINKA plots were established in 1984–1986 and remeasured once in 1989–1991. The SUOJAINKA plots were measured in northern Finland for the first time in 1978–1980 and remeasured 10 years later in 1989–1990. The peatland forest growth plots (SINKA) were established 1984–1988 and they have not all been yet remeasured once.

The aim in establishing these plots is to obtain empirical material for growth and yield models suitable for stands treated in accordance with silviculture applied in today's practical forestry. The locations of the plots are randomly selected from the NFI temporary plot material. Some restrictions concerning tree species, sites and stand characteristics have been made.

The permanent plot cluster consists of three single plots located in the same stand 40 metres apart from each other. The size of the plots depends on the density of the stand. The average number of measured trees in a stand is 100–120 trees. In older stands this means a size of 0,1–0,2 hectares for all three plots together. The plot size will be enlarged when stem number decreases due to thinnings.

About 30–40 sample trees per cluster are selected from among the tallied and mapped trees. The measurements are roughly the same as in the above mentioned NFI permanent plots. In TINKA, SINKA and SUOJAINKA plots some additional tree characteristics like the number of needle years and the amount of branches will be measured or estimated.

FELLED SAMPLE TREES ON NFI-PLOTS

In 1987 a single tree study, VAPU (National Tree Research Project), was started at the Finnish Forest Research Institute. The aim of this ambitious research project was to collect single tree data for developing models for several tree characteristics needed in forest inventory and management planning. About 3000 sample trees covering the whole country were to be felled and measured in the period 1987–1995. The selection of sample trees was bound to NFI7 and NFI8 systematic tracts. From each inventory tract 3 plots will be selected and on each plot 3–6 felled trees will be measured. To date about 650 felled sample trees have been measured on 114 temporary plots.

The data collecting focuses on standing and felled trees. Standing trees will be measured for dbh, height, crown size plus direction and distance from the mid point of the plot. The health of each standing tree will be estimated.

In the case of felled sample trees, diameters are measured over and under bark at 1,3 and 6 metres and additionally at 16 relative heights along the stem. The height growth, diameter and location of branches, the amount of needles in different needle years and the weight of sample branches are also measured. Three branches and 10 sample discs from the stem will be analysed for biomass and increment in the office. All these measurements make it possible to prepare models for predicting the development of tree dimensions, biomass and technical quality (branchiness). The objective selection of sample trees guarantees the applicability of these models throughout Finland.

UTILIZATION OF THE EMPIRICAL MATERIAL

A vast amount of different growth and yield models has been constructed during the past decades. Most of them are based on limited temporary materials and they cannot be recommended to be used in management planning for large areas. For these kinds of long-term predictions the growth model has to fulfil the following demands:

First, the model must be logical over large range of different variables and their combinations. This cannot be easily guaranteed, if the variation in the empirical material is limited. The best data in this respect can be found in experiments, where highly exceptional treatments have also been applied. The need for theoretical thinking in choosing predictors for the model is naturally of great importance.

In spite of theoretical intelligence the model must also fit in with the measured reality. That is why models must always be tested using an independent test material. The level of model predictions can be calibrated by measured data, if the model is unbiased with regard to predictor variables.

The biggest problem in predicting future growth is the possible environmental change. In theory, process models in which the effect of the environment on tree physiology is modeled in a very detailed way are the best way to meet this problem. Unfortunately, process models are still far from being practical in forest management planning. In the future, the compromise between statistical and process models could be so-called hybrid models, in which some process elements will be incorporated in statistical models (Kimmins et. al. 1988).

The vast empirical material described in this paper can be used for growth modelling in many ways. The most logical sequence is to begin modelling with the most accurate material with the largest variation in predictor variables. The felled sample trees in VAPU and the latest controlled experiments form the most logical basis to start contructing new models.

The oldest experiments offer the first material to test the bias of the models in a long time-span. The regional calibration of model predictions can at last be done by objectively collected data in the network of National Forest Inventories. The need for measuring calibration data at short intervals is of importance.

REFERENCES

Ilvessalo, Y., 1932: The establishment and measurement of permanent sample plots in Suomi (Finland). Selostus: Pysyvien koealojen perustaminen ja mittaus Suomessa. Commun. Inst. For. Fenn. 17.2:1–39.

Kimmins, J.P., Scoulla, K.A., Comeau, P.G., Kurz, W.A., Apps, M.J., & Chatarpaul, L. 1988: FORCYTE–11; An example of the hybrid simulation approach to predictind the consequences for production, yield, economics, soil fertility, nutrient and organic matter reserves, and energy efficiency of alternative crop production systems. In: Ek, A.R., Shifley, S.R. & Burk, T.E (eds.). 1988. Forest Growth Modelling and Prediction, Proceedings of the IUFRO Conference, August 23–27, 1987, Minneapolis, Minnesota, vol. 1, pp. 22–32.

Kuusela, K. 1978: The national forest inventory in Finland. IUFRO (Proceedings), Joint meeting of IUFRO groups S4 02 and S4 04, Theme: National forest inventory, Bucharest, Romania, pp. 368–377.

Mäkelä, H. & Salminen, H. 1991: Metsän tilaa ja muutoksia kuvaavia puu- ja puustotunnusmalleja. Metsäntutkimuslaitoksen Tiedonantoja 398. Joensuun tutkimusasema, 265 p.

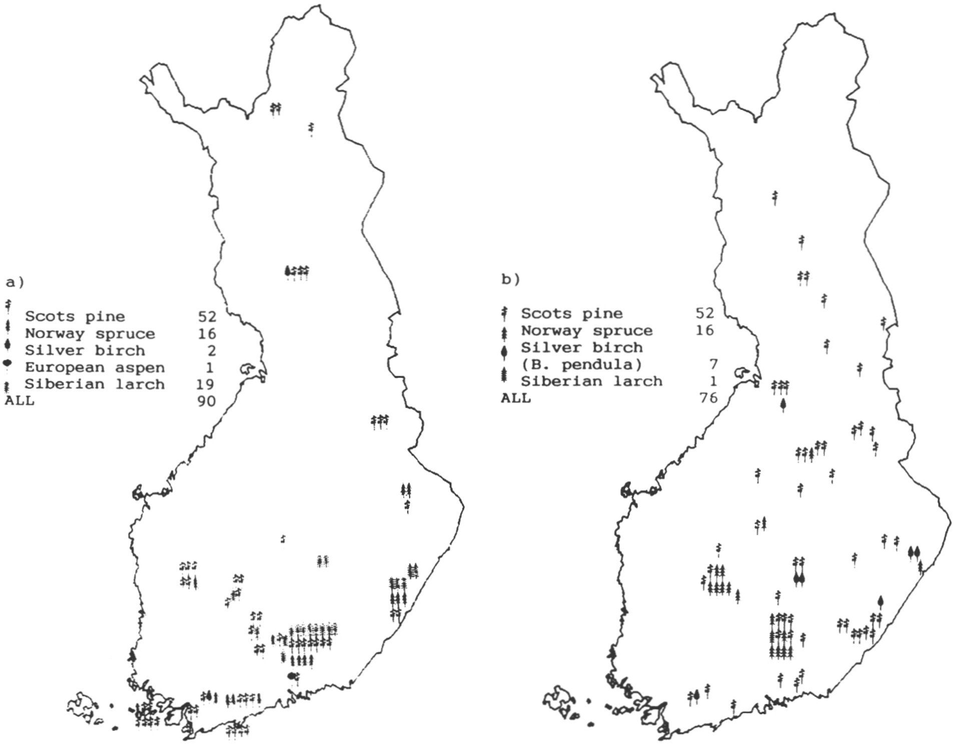


Figure 1. Examples of permanent plots in subjectively selected experimental stands in Finland; a) the "old" thinning experiments (173 single plots), b) experiments treated with repeated thinnings (HARKAS-experiments, 562 single plots).

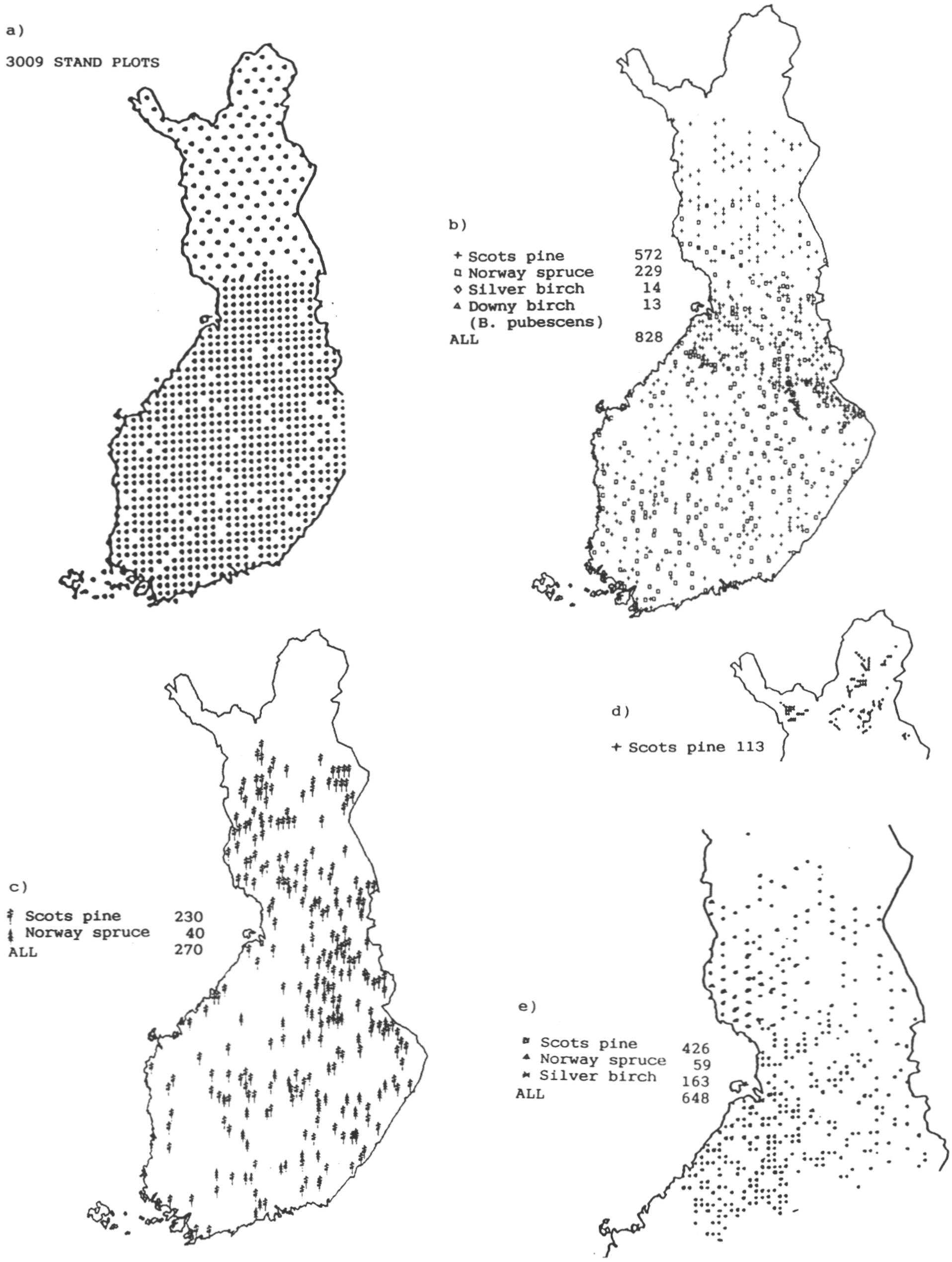


Figure 2. Permanent stand plots established since 1976 on the NFI tracts; a) the NF18-plots, b) the INKA-plots in older stands, c) the TINKA-plots in young stands, d) the SUOJAINKA-plots in protection forest stands, e) the SINKA-plots in peatland forest stands.

TREE VOLUME ESTIMATION AND SAMPLE TREE SELECTION IN THE SWISS NFI

Edgar Kaufmann
Swiss Federal Institute for Forest, Snow, and Landscape Research (WSL),
Birmensdorf, Switzerland

ABSTRACT

The volume functions used in the first Swiss National Forest Inventory (NFI) were developed from stem analysis data of cut sample trees on growth and yield research plots. Analysis, in which the data from NFI-plots and data from the growth and yield plots were compared showed, that stem forms of NFI sample trees have a greater variability than the available stem analysis data. Therefore, additional measurements have been taken and new volume functions are now being constructed.

Bole volume functions, the form of the tariff function and the method chosen to describe taper curves for the species spruce are presented. Robustness and precision of the different types of functions are compared.

All trees on the circular NFI sample plots are calipered. A subsample of trees in each plot is measured for an upper stem diameter and tree height. Alternative sample tree selection procedures for the second NFI have been studied. Volumes per plot are calculated using the predictions of both volume functions and tariff functions in a way, that the error component arising from the tariff regression function is included in the sampling error and volume estimates are unbiased even in small strata.

Keywords: Forest inventory, volume functions, stem profile models, inventory sample tree selection

INTRODUCTION

The first Swiss NFI was conducted from 1983–1985. After completion of the inventory, the stem analysis data, from which the single tree volume functions used in NFI had been derived, were compared with the inventory trees. It was found that the stem analysis data did not cover the whole range of tree forms of NFI. Moreover, average h/dbh ratios (total tree height divided by diameter at breast height) of stem analysis trees are systematically greater than those of inventory trees. Gertner and Köhl (1992) have found that the Swiss NFI system is extremely sensitive to systematic bias. Additional stem analysis trees are now measured for these reasons and new volume functions are constructed.

Bole volume functions of the form v=f(dbh,d7,h) are derived from stem analysis data (d7=diameter at 7m height). In NFI, only a subsample of trees, the so called tariff trees, is selected for measuring d7 and h and thus for determining tree volumes with this type of functions. All trees are measured for dbh. Tariff functions (one way volume functions with dbh as the only measured tree variable) have been elaborated using the predicted bole volumes of the tariff trees as dependent variable in the regression. The bole volumes of all trees are then estimated with these tariff functions.

In the paper, a new derived bole volume function (v=f(dbh,d7,h)) and a modified method for describing stem profiles are presented as well as some aspects of validation. The tariff function used in first NFI is described. The presentations are limited to spruce. With a portion of about 40%, spruce is by far the most frequent species in Swiss forests (EAFV 1988).

In the first NFI, the tariff trees were selected in a limited plot sector with three different selection probabilities corresponding to the dbh class of the trees. PPS (=probability proportional to size) selection procedures, where selection probability is continuously increasing with increasing tree size, have been found to be more efficient. The portion of selected trees can be reduced without considerable loss of precision. For that reason, a PPS selection procedure is proposed to apply in the second NFI.

The residuals of the tariff regression functions will also be used in the second NFI for volume per area estimates by weighting them inversely proportional to the selection probability of the tariff trees (Mandallaz 1991). The estimates are unbiased even in small strata and random errors arising from the tariff regression functions are included in the sampling error.

VOLUME FUNCTIONS

Stem Analysis Data

The stem analysis data have been collected during decades by the yield research group of the WSL. Diameters of felled trees in growth and yield research plots have been measured in 2m sections. Tree volumes are calculated by frustums of cones. For species spruce, about 12800 stem profiles are available. In addition, diameters at different relative tree heights of 200 standing spruces of big size have been measured mainly in the alpine region with the TODIS dendrometer (Eller and Keister 1979). This instrument allows very precise diameter measurements. Tree volumes were calculated using cubic splines (Kleinn 1989). These data were merged in the stem analysis data.

Tariff Tree Measurements in NFI

In NFI, tariff trees are measured for dbh as well as for an upper diameter at 7m with finnish caliper and for total tree height with Christen altimeter. The combination of these instruments was found to be most efficient in terms of precision and time consumption (Schmid-Haas and Winzeler 1981, Winzeler 1986 a). Finnish caliper has proved to be more precise than usual optical calipers. Only when measurement errors are not taken into account, volume functions with an upper diameter measured at a relative tree height are more precise. Trees in the Austrian NFI for example are measured for an upper diameter at 30% tree height (Haszprunar 1985). When applied on Swiss stem analysis data, the standard deviation of the residuals of the Austrian volume function for spruce (Braun 1969) is about 20% smaller than that of the Swiss volume function (model 1). The NFI 1 measurement methods will not be changed in NFI 2 in order to keep tree volumes of successive inventories comparable.

Bole Volume Function

Over bark bole volume of spruce is predicted by a linear regression model of the form:

$$v=b_0 + b_1{*}h + b_2{*}dbh^2 + b_3{*}d7^3 + b_4{*}d7^2h \qquad \text{Model 1}$$

b_0–b_4: regression coefficients (see table2)
h: total tree height (m)
dbh: diameter at breast height (m)
d7: diameter at 7m height (m)

Table 1: Single tree volume predictions: goodness of fit of model 1 (bole volume function for spruce) and model 2 (Splines).
AR: average residual in % of the mean tree volume, SR: standard deviation of the residuals in % of the mean, P_t:Probability of the t-distribution for |AR|=0, VE: Percent variation explained, n: number of trees

Model		Diameter at breast height (cm) 12–23	24–35	36–47	48–59	60–71	72–83	84–95	>95	total
	AR	0	0	0.1	–0.2	–0.3	0.9	0.5	0	0
1	SR	3.6	3.6	4.0	4.5	5.1	3.8	3.6	3.8	6.5
	P_t	0.55	0.75	0.31	0.2	0.38	0.07			0.88
	VE									99.70
	AR	0	–0.6	–0.7	–0.5	0.4	2.1	1.7	1.3	–0.3
2	SR	3.7	3.7	4.0	4.3	5.4	5.1	5.5	1.6	7.0
	P_t	0.45	0	0	0	0.30	0			0
	VE									99.66
	n	6622	3521	1780	779	253	60	11	3	13029

Table 2: Regression coefficients and their standard errors of model 1 (new bole volume function for spruce) t: t-value of the t-distribution

Model 1	All trees in analysis (n=7020)			Jackknife (20 groups)		
Par.	Coeff.	Std.err.	t	Coeff.	Std.err.	t
1	2	3	4	5	6	7
b0	0.0294	0.0014	20.3	0.0295	0.0028	10.5
b1	–0.0018	0.0001	–18.4	–0.0018	0.0002	–9.0
b2	2.4334	0.0261	93.4	2.4389	0.0651	37.5
b3	–5.729	0.1664	–34.4	–5.7466	0.2501	–23.0
b4	0.4675	0.0025	190.4	0.4676	0.0030	155.9

Error variances were found to be proportional to $d7^3h$. In order to homogenize them, least squares were weighted with the reciprocals of the estimated error variances ($1/(d7^3h)$). For the estimation of the coefficients, sample trees with dbh 12 cm (caliper threshold) to 35 cm were selected from the sample data with probability proportional to their dbh. The same regressor variables were used in a study by Winzeler (1986 a), but he had estimated coefficients with ordinary least squares regression.

Table 1 shows, that the average differences between volume predictions and stem analysis data volumes (AR) are not different from zero at the 95% level in all diameter classes. The standard deviation of the residuals (SR) is 6.5% of the mean tree volume. 99.7% of the variation is explained by the model.

Aspects of Validation

Standard errors of regression coefficients: Due to the high correlations between the regressor variables of the volume function, these standard errors can be underestimated. Nonparametric standard errors of the regression coefficients were thus computed using the Jackknife algorithm.

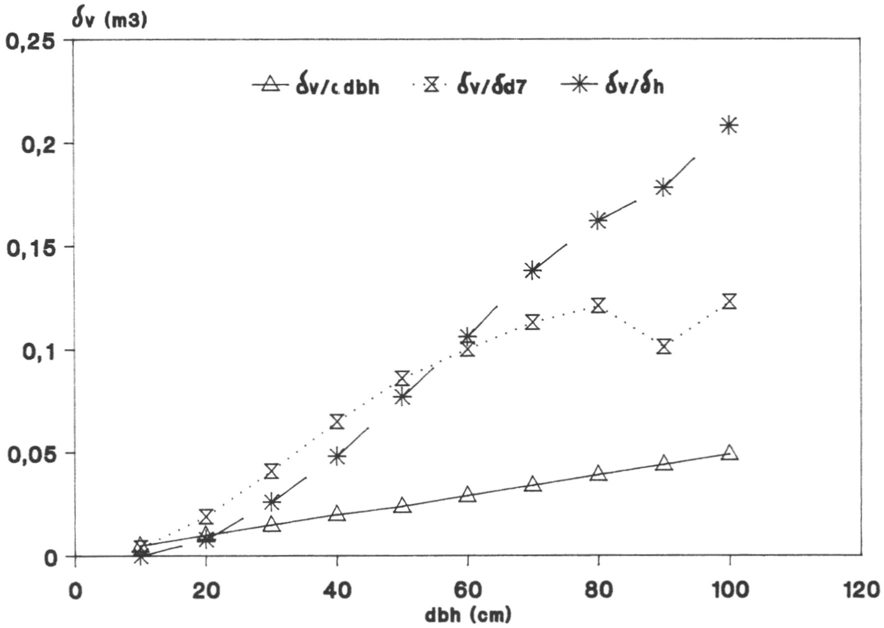


Fig. 1: Change in bole volume (δv,m$^{3)}$ with increasing dbh,d7 and h: partial derivatives of model 1 (new bole volume function for spruce) with respect to dbh (δdbh, ddbh=1cm), d7 (δd7, dd7=1cm) and h (δh,dh=1m). Average d7 und h of NFI inventory data were taken for each dbh class.

The Jackknife is a sample reuse method, where statistics are repeatedly recomputed from the same data, but with one or more observations removed from the analysis in each iteration (Miller 1974, Efron 1982). The high amount of data requires application of a grouped Jackknife (Efron 1982, p.7): data were splitted into 20 groups of equal number of observations. One group was deleted from the data set in each iteration. The statistics were computed as follows (derivation of formulas see Miller 1974 and Efron 1982):

Jackknife estimate of the regr.coeff. ($\tilde{\Theta}$): $\tilde{\Theta} = g \cdot \hat{\Theta} - (g-1)/g \sum_{i=1}^{g} \hat{\Theta}_{-i}$

Jackknife std.err. of regr. coeff. ($V(\hat{\Theta})$): $V\left(\hat{\Theta}\right) = (g-1)/g \sum_{i=1}^{g} \left(\hat{\Theta}_{-i} - 1/g \sum_{i=1}^{g} \hat{\Theta}_{-1} \right)^2$

where: g : number of groups
$\hat{\Theta}$: estimates based on the whole sample
$\hat{\Theta}_{-i}$: estimates with the ith group deleted from the sample

Jackknife estimates of variances tend to be conservative, they are ".. if anything, biased moderately upward'' (Efron 1982, p.21). As it is shown in table 2, the jackknife standard errors of the regression coefficients (column 6) are greater than those computed in the usual way (column 3). However, the t-values for the jackknife estimates indicate, that all regression coefficients are still significantly different from zero at the 95%level ($|t|>2$) and therefore useful in the regression.

Sensitivity: How sensitive a function reacts to changes of dbh, d7 or h was tested by derivating it with respect to these three measured parameters. Change in volume was calculated by increasing one parameter at a time by one measurement unit (dbh: 1cm, d7: 1cm, h: 1m) and keeping the other two constant. Fig. 1 presents the first partial derivatives with increasing dbh. For each dbh-class, mean form ratios (h/dbh and d7/dbh) of NFI data were taken for calculating the derivatives. The function was derivated for dbh= 10cm, 20cm, 30cm... The resulting curves are monotonously increasing with increasing dbh: the greater a tree size, the greater is the volume increment when a measurement is augmented by one unit. It can also be seen here, that the influence of d7 on change in volume is much bigger than the influence of dbh. That is because dbh often lies near the buttresses of the trees. The first partial derivatives for all combinations of dbh, d7 and h that occurred in NFI, are positive, except the slight negative values for trees with d7 < 6 cm. Single tree volume is thus always increasing, when a measurement unit is increasing. This is an important property for determining growth.

Analysis of covariance: An analysis of covariance has shown, that the regression coefficients are different for flat and alpine geographical regions. However, the variance reduction which can be achieved by elaborating regional models is small. The application of one overall model is therefore justified.

Tariff Function

The volumes of all trees in NFI were determined with a tariff function, a function with dbh as the only measured tree size. Additional tree and stand characteristics were used for grouping or were introduced as independent variables into the function. As dependent variables, the volume predictions of the NFI tariff trees were used. The basic tariff model was developed by Hoffmann (1982). It was then adapted for NFI by Winzeler (1986 b). The function will be modified for the second NFI.

Tariff volume:

$$TV = D_i * \exp\left[b0_i + \sum_{j=1}^{10} b1_{ij} * ZZ_j + b2_i * \ln(dbh) + b3_i * \ln(dbh)^4 \right]$$

$i= 1..58$: tariff groups. A function was derived for each group, 19 of that for spruce. A group was defined by tree species, development stage, crown density and number of storeys of a forest.

$j= 1..\ 10$: index for stand and tree variables

ZZ_j : stand and tree variables such as geographical region, site index, social position of a tree and others (totally 10 variables).

D_i : Bias correction factor (logarithmic transformation was used to estimate the function parameters with linear ordinary least squares regression).

b0–b3 : regression coefficients

This function is much less precise (stand. dev. of residuals 24.8%) than bole volume functions of the form of model 1 (stand. dev. of residuals 6.5%).

Taper Curve Function

Beside total bole volumes, also log volumes to any merchantable limits are estimated in NFI. For this purpose, stem profiles are modelled in order to predict upper stem diameters.

This is done in three steps:

1. Diameters at any relative tree height are highly correlated with dbh, d7 and h. Some diameters at relative heights are thus predicted directly as a function of dbh, d7 and h:

d_i * d7/dbh = $b_0 + b_1$*d7 + b_2*h + b_3*dbh*h + b_4*d7*h
weight of least squares: $(dbh/d7)^2$ (bias correction
due to transformation of dependent variable)

d_i: diameters at relative tree heights of i= 1%, 10%, 20%, 30%, 50%, 70%, 80%.

2. Stem profiles are then described by cubic interpolation splines (Kleinn 1989) with knots at the relative tree heights mentioned above.

3. In a last step, the splines are adjusted to pass through measured dbh and d7. The linear adjustment is additive and inversely proportional to the distance of some location (h_i) to the location of a measured diameter (dbh,d7):

$$da_i = d_i + (h_i - a)/b * \left(d7 - d\hat{7}\right) + (1 - (h_i - a)/b) * \left(dbh - d\hat{b}h\right) \qquad \text{for } h_i <= 7\text{m}$$

$$da_i = d_i + \left[1 - (h_i - c)/(H - c)\right] * \left(d7 - d\hat{7}\right) \qquad \text{for } h_i >= 7\text{m}$$

$d_1, d\hat{7}, d\hat{b}h$:	diameters obtained by spline interpolation
da_i:	adjusted diameter
H:	total tree height
a:	1.3m (height of dbh)
b:	5.7m (distance between d7 and dbh)
c:	7m

This method is in the following called model 2. The approach is similar to one chosen by Laasasenaho (1982). His diameter prediction equations however are different from those presented here. Also he had used polynomial adjustment functions.

The taper curve model for spruce used in first NFI was developed by Roiko-Jokela (1976). He calculated individual functions for different part intervals along the stem. The functions are continuous at the common knot points. In table 3, model 2 is compared with the model of Roiko-Jokela (model 3). Coefficients of model 2 and model 3 are based on the same sample data for that reason. Tree height class 30m–35m is depicted. Mean deviations and their standard deviations in intervals of two meters along the stems are comparable. The overestimation of model 2 at height 3m is due to the extreme concavity of trees with great dbh and small form ratio (d7/dbh). This bias is acceptable. The underestimation of –2cm at 1m height of model 3 arises from the assumption of a cylindric stem basis. The new model also underestimates this diameter. The deviations at 1m height are of minor importance, because buttresses are cut off when trees are harvested. The main advantage of model 2 compared with model 3 is its simplicity and transparency. It can easily be recalibrated whenever additional stem analysis data are measured. The development steps (estimation of diameters, spline interpolation, adjustment of diameters) are independent of each other and can be modified without affecting each other.

Bole volumes estimated with the taper curve model (model 2) are less accurate than those computed with the bole volume function (model 1, see table 1).The taper curve model slightly underestimates stem analysis data (–0.33%). Its precision (7.0%) is slightly lower than that of model 1 (6.5%).

Applying Models on NFI – Data

NFI data is completely independent of the stem analysis data, from which the tree volume models have been derived. The stem profile models and bole volume functions are mathematically not compatible.Therefore volume predictions of NFI data can differ. Mean volume differences (AD) and standard deviations of the differences between models (SD) using NFI data are presented in table 4. Bole volume and taper curve models used in first NFI (3,4) and corresponding new models (1,2) are compared. The big deviations between the former models (3–4) for big tree dimensions (dbh>80 cm) is due to the lack of stem analysis data. The new taper curve function tends to a positive deviation from the bole volume function with increasing dbh. The mean deviations between old models (3–4) are in the same order of magnitude as those between the new models (2–2). These differences are acceptable The standard deviations of the differences between the new models are smaller than those between the old models.

Table 3: Means ($\overline{x}$, cm) and standard deviations (s_x, cm) of the differences between predicted and measured diameters.

Tree height class H= 30–35 m

		Model 3 (Roiko)		Model 2 (Splines)	
Height (m) ab. ground	n	$\overline{x}$(cm)	s_x (cm)	$\overline{x}$(cm)	s_x (cm)
1	2517	–2.04	1.30	–1.30	1.24
3	2517	–0.24	0.84	0.44	1.00
5	2517	–0.09	0.60	–0.13	0.60
7	2517	0		0	
9	2517	0.02	0.55	0.06	0.57
11	2517	0.02	0.69	0	0.71
13	2517	0	0.83	–0.03	0.84
15	2517	0	0.97	0	0.99
17	2517	–0.03	1.14	–0.02	1.16
19	2517	–0.06	1.26	–0.04	1.29
21	2517	–0.07	1.39	–0.06	1.42
23	2517	–0.09	1.50	–0.11	1.52
25	2517	–0.33	1.53	–0.16	1.52
27	2517	–0.78	1.45	–0.28	1.42
29	2517	–1.07	1.22	–0.46	1.21
31	1916	–1.00	0.99	–0.51	0.95
33	991	–0.85	0.78	–0.52	0.73
35	198	–0.50	0.44	–0.37	0.41

Table 4: Average bole volume differences between models (AD) in % of the mean and standard deviations (SD) of differences in % of the mean. Estimated tree volumes of the NFI inventory data (species spruce).

1 new bole volume function for spruce, 2 new taper curve function
4 old bole volume function for spruce, 3 old taper curve function

		Diameter at breast height (cm)								
Model		12–23	24–35	36–47	48–59	60–71	72–83	84–95	>95	total
3–4	AD	–2.3	–2.2	–2.4	–1.6	–0.6	–1.6	–5.8	–21.5	–1.9
	SD	6.8	3.0	1.8	2.5	5.1	10.8	21.6	39.4	12.8
2–1	AD	0.1	–0.2	–0.2	0.7	1.9	2.8	5.2	3.0	0.8
	SD	3.3	1.9	1.2	1.4	2.1	3.3	5.2	9.4	3.9
	n	4985	3675	6005	2678	1738	431	70	23	19605

VOLUMES PER AREA UNIT

Volumes per plot are computed with a tariff function, which is derived from NFI tariff trees. The residuals of this function are also used in computation. These residuals are the differences between predictions with the tariff function and predictions with the bole volume function. They are only known for tariff trees, which are a subsample of all trees. Therefore, they are weighted inversely proportional to the selection probability of the tariff trees (Mandallaz 1991):

Volume of plot x: $$\hat{Y}(x) = \sum_{i \varepsilon S_1(x)} f_i \cdot \hat{Y}_i + \sum_{i \varepsilon S_2(x)} f_i \cdot \frac{\varepsilon_i}{P_i}$$

Expected value of $\hat{Y}(x)$: $$\hat{Y} = \frac{i}{n} \sum_{x=1}^{n} \hat{Y}(x)$$

Variance of $\hat{Y}$: $$\hat{V}\left(\hat{Y}\right) = \frac{1}{n(n-1)} \cdot \sum_{x=1}^{n} \left(\hat{Y}(x) - \hat{Y}\right)^2$$

$\hat{Y}_i$: tariff volume of a single tree
$\hat{Y}(x)$: volume of plot x
$\hat{Y}$: expected value (volume/ha)
ε_i : residual of tariff function
$\varepsilon_i = Y_i - \hat{Y}_i$, where Yi=predicted bole volume with function v=f(dbh, d7, h)
$s_1(x)$: sample of all trees on plot x
$s_2(x)$: subsample on tariff trees on plot x
fi : expansion factor
pi : selection probability of tariff trees

The volume per area estimates calculated in this way are unbiased, when volumes predicted with bole volume functions (v=f(dbh,d7,h) are considered as the true tree volumes (Mandallaz 1991). Errors arising from the use of regression models, especially those of one way volume tables, are among the most important error components in forest inventories (Cunia 1990). In an error budget, which was developed by Gertner and Köhl(1992) for Swiss NFI it was found, that after sampling error the variability due to the tariff functions is next in importance. When calculating volumes per area unit with the estimator presented above, this variance component is included in the sampling error.

SELECTION OF TARIFF TREES

NFI plots are concentric circles of 200 m^2 and 500 m^2. Within the smaller area, all trees with dbh>11cm are registered, within the bigger area only those with dbh > 35cm. In the first NFI, tariff trees have been trees in a plot sector of 0–150 degrees and all trees in a plot with dbh >= 60 cm (Zingg and Bachofen 1988). A portion of 35% of all trees was selected as tariff trees.

If the residuals of the tariff function are used for volume per plot calculation as presented here, the standard error of the mean volume/ha increases with decreasing number of selected tariff trees. Alternative tariff tree selection procedures have been studied. Trees were selected with a probability proportional to dbh, to dbh^2 and with a probability proportional to the prediction error of the tariff function (PPE). This prediction error was estimated by a regression model. Although only 50% of the variation could be explained by this model, the PPE selection procedure is as efficient as the two other PPS procedures, as is shown in figure 2. Figure 2 presents the standard error for the mean volume/ha for different numbers of tariff trees and different selection prosedures. PPS procedures are more efficient than the selection procedure of the first NFI (called "random sample" in fig. 2), especially when a small number of tariff trees is drawn.

The optimum number of tariff trees (total cost for tree measurements * variance between plots=minimal) is at 16.000 trees (13%) for the selection procedure of NFI 1 and at about 10.000 trees (8%) for the PPS and PPE procedures. The optimization was based on the NFI 1 plot grid of 1*1 km covering the whole country. That is a total of 11.000 plots with totally 128.500 trees. The portion of tariff trees is proposed to be reduced in NFI 2. A subsample of NFI 1 tariff trees should be drawn with selection probability proportional to dbh^2. The definitive number of tariff trees will also depend on the number of terrestrial plots that will be recorded in the second NFI.

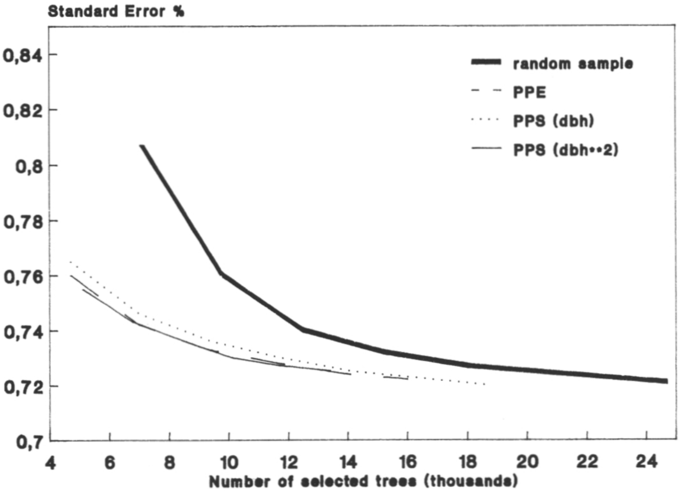


Fig. 2: Standard error in % of the mean volume/ha in NFI, assuming 11000 terrestrial plots are recorded, for different tariff tree selection procedures and numbers of trees selected.

Random sample:subsample of all inventory trees with 3 different selection probabilities according to dbh-classes. PPS: selection proportional to dbh or dbh^2. PPE: selection proportional to prediction error.

CONCLUSION

Measurements of additional stem analysis data is necessary in order to reduce the extrapolation area of the volume functions used in NFI. The development of new functions is reasonable. New volume functions based on an extended set of stem analysis data are more stable. The tree measurement methods used in NFI 1 remain unchanged.

A relatively simple approach for describing stem profiles allows easy recalibration of the models whenever additional stem analysis data are measured.

It is recommended to modify the tariff tree selection procedure for the second NFI. Tariff trees for volume determination as a function of dbh, an upper diameter and tree height are proposed to be selected with probability proportional to dbh^2. The portion of tariff trees should be reduced.

REFERENCES

Braun, R. 1969: Oesterreichische Forstinventur. Methodik der Auswertung und Standardfehler-Berechnung, Mitt.Forstl.Bundes-Vers.anst. Wien, Nr.84., 60 p.

Cunia, T. 1990: Forest Inventory: On the Structure of Error of Estimates, in: US Forest Service Pacific Northwest Research Station, General Techn. Report PNW-GTR-263, Symposium Proceedings, p. 169–180

EAFV 1988: Schweizerisches Landesforstinventar: Ergebnisse der Erstaufnahme 1982–1986, Eidg.Anst.Forstl.Versuchswes., Ber. 305, 375 p.

Efron, B.1982: The Jackknife, the Bootstrap and Other Resampling Plans, Soc. for Ind. and Applied Mathematics, Philadelphia, 92 p.

Eller, R. C.; Keister, T.D. 1979: The Breithaupt Todis Dendrometer, Southern Journal of Applied Forestry, 2, p. 29–32

Gertner, G.; Köhl,M. 1992: An assessment of some nonsampling errors in a national survey using an error budget, For.sci.(in press)

Haszprunar, H. 1985: Die österreichischen Forstinventuren, Mitteilungen der Abt. forstl. Biometrie Universität Freiburg Nr. 3, p. 83–105.

Hoffmann, Ch. 1982: Die Berechnung von Tarifen für die Waldinventur, Forstwiss.Cent.bl., 101/1, p. 24–36

Kleinn, Ch. 1989: Zur Berechnung von Einzelbaumvolumen, Mitteilungen Abt. Forstl. Biometrie Universität Freiburg, Nr.1

Laasasenaho, J. 1982: Taper curve and volume functions for pine, spruce and birch, Communicationes instituti forestalis fenniae, Nr. 108, 74 p.

Mandallaz, D. 1991: A Unified Approach to Sampling Theory for Forest Inventory Based on Infinite Population and Superpopulation Models, Diss. ETH-Zürich, Lehrstuhl Forstinventur und Planung, 256 p.

Miller, R. G. 1974: The jackknife- a review, in: Biometrika, Vol. 61, No. 1, p. 1–15

Roiko-Jokela, P. 1976: Die Schaftformfunktion der Fichte und die Bestimmung der Sortimentsanteile am stehenden Baum, Mitt. Eidg.Anst.Forstl.Versuchswes., Vol. 52, Nr. 1, p. 1–84

Schmid-Haas, P.; Winzeler, K. 1981: Efficient Determination of Volume and Volume Growth, in: Proceedings 17th IUFRO World Congress, Kyoto,Japan, p. 231–257

Winzeler, K. 1986 a: Volumenbestimmung durch Messungen am stehenden Baum, Mitteilungen Eidg.Anst.Forstl.Versuchswes., Vol. 62, Nr. 1

Winzeler, K. 1986 b: LFI-Tariffunktionen, internal WSL-report, unpublished

Zingg, A., Bachofen, H .H. 1988: Schweizerisches Landesforstinventar, Anleitung für die Erstaufnahme 1982–1986, Ber.Eidg.Anst.Forstl.Versuchswes. Nr. 304, 134 p.

TREE MODELS FOR BIOMASS ESTIMATION IN *EUCALYPTUS* AND *PINUS* INVENTORIES IN BRAZIL

Ricardo Antonio De Arruda Veiga
Department of Forest Sciences
FCA / UNESP
Botucatu, S.P–Brazil

ABSTRACT

Forest inventories made in Brazil, seldom consider biomass quantification in terms of dry matter production, in spite of the importance of this type of characteristic.

In the present paper several studies previously published by the author are summarized, selecting regression models to express the total stem dry weight of *Eucalyptus and Pinus* tree species, with several ages, and planted in different locations, as a function of dbh outside bark and total height. Collected data concerning branches and cannopy weight are also included.

Original results concerning individual models to a variable –top dry weight prediction for *Pinus elliottii var. elliotti* (145 trees, 5 age classes from 16 to 24 years) and *Pinus caribaea var. caribaea* (88 trees, 3 age classes from 6 to 14 years) are presented.

INTRODUCTION

Forest tree plantation inventories had evolved in a great degree in Brazil, in quality as well in quantity after the seventhies, but quality is still inferior when compared to inventories realized in several countries.

The utilization of volume equations, seldom utilized before is now a disseminated practice in inventory projects. However the utilization of weight equations is still uncommon, even considering the similarity with volume equations and the importance of the former on biomass quantification studies. In those regression models, the dry weight of individual tree stem is predicted as a function of diameter breast height (dbh) and total height.

In the present paper several results obtained from biomass studies of *Eucalyptus* and *Pinus*, in Brazil, are summarized. Regression models for estimating dry weight without bark, for entire tree and merchantable stem sections, selected for different species, growing under different conditions are presented. Collected data concerning tree branches and canopy are included.

Original results concerning individual models to a variable –top dry weight prediction for *Pinus elliotti* var. *elliotti* and *Pinus caribaea* var. *caribaea* are also presented.

MODELS FOR EUCALYPT TREES

The first brazilian papers published on models for estimating the wood dry weight of tree stems as function of dbh and total height were those from Veiga and Brasil 1981 and Veiga, Brasil and Ferreira 1981.

Both papers were conducted for eucalypt stands and were previously presented in a IUFRO meeting hold in Brazil, with summaries published in 1980.

Veiga and Brasil 1980, and 1981, collected data from 140 trees of five years old *Eucalyptus propinqua* Deane ex Maiden plantations in two different sites of São Paulo State, Brazil. These sample trees were used to develop a general model for the prediction of stem dry weight (W) without bark to 0.05m diameter top, from dbh outside bark (D) and total tree height (H). The selected model, with regression coefficient $r^2 = .9535$, was $W = -.62611 + .01330\ D^2 H$, where W is given in kg, D in cm and H in m. Volume equations were also selected.

Veiga, Brasil and Ferreira 1980, and 1981, worked with data collected from 5 and 7 years old *E. saligna* Smith and *E. urophylla* S.T. Blake plantations. The regression equations selected for the merchantable stem dry weight were $W = -5.0146 + .01595443\ D^2 H$, and $W = -4.28 + .01672391\ D^2 H$, with $r^2 = .8836$ and $.9458$.

An eucalypt biomass forest inventory, in terms of dry matter by hectare, was conducted by Veiga et al. 1985 in the State of Minas Gerais. Regression equations were calculated for 5 age classes, predicting dry matter weight, without bark, for total stem and for merchantable weight up to three diameter tops. The model was the Spurr's combined variable

$$W = bo + b1\ D^2 H$$

as follows:

Eucalypt Age	b_i	Total Weigh	Merchantable Weight .03m	.07m	.12m
4 yrs.	bo	–.1352	– .7456	–2.7134	–1.7332
	b1	.0125	.0118	.0114	.0088
6 yrs.	bo	–.1238	– .6851	–3.3139	–1.0856
	b1	.0129	.0122	.0121	.0090
7 yrs.	bo	–.5213	–1.2427	–4.5415	–3.6750
	b1	.0140	.0135	.0136	.0110
9 yrs.	bo	–.2896	– .7997	–4.4578	–4.3296
	b1	.0143	.0136	.0142	.0117
10 yrs.	bo	–.7091	–1.2661	–4.8930	–2.8114
	b1	.0159	.0152	.0151	.0108

MODELS FOR PINE TREES

For pine trees, the first papers concerning weight equations were published by Brasil, Veiga and Coelho 1982 and Montagna et al. 1983. Both summaries were also previously published in 1980, after presented in a IUFRO meeting in Brazil.

In order to determine the stem dry weight without bark up to .04m top diameter outside bark, 101 Slash Pine (*Pinus elliottii*) trees were cut off in three different sites of São Paulo State (Brasil, Veiga and Coelho 1980, 1982). Several models were studied, selecting the equations $\ln W = -5.44686333 + 1.71136277 \ln D + 1.776049 \ln H$, with $r^2 = .8772$.

Data were collected from 45 trees of 17 years old *Pinus caribaea Mor. var. hondurensis* Bar et Golf. from different spacings in Mogi Mirim, São Paulo State. The stem dry weight without bark up to .08m top diameter was better estimated by the equation $W = 9.858582 + .008459\ D^2H$ (Montagna et al. 1980, 1983), with $r^2 = .8996$.

After that other studies were conducted by the author as well by a small group of researchers in Brazil, and some of them are summarized as follows.

Brasil, Veiga, Coelho and Montagna 1983 collected data from 5 pine species trees 20 years old, in order to determine the total and merchantable stem dry weight, in ton/hectare/ year. The total and merchantable (.03m diameter top) stem dry weight were estimated by the combined variable model $W = bo + b1\ D^2H$ as follows:

Pinus spp	b_i	Total Weight	Merchantable Weight .03m
P.caribaea	bo	−16.535644	−17.148292
var. hondurensis	b1	.014880	.014577
P. kesiya	bo	− 4.847108	− 5.058288
	b1	.013424	.012984
P. patula	bo	3.188915	2.679778
	b1	.012598	.012126
P. elliottii	bo	5.955747	5.175008
	b1	.014081	.013574
P. montesumae	bo	1.963467	1.393597
	b1	.009436	.008845

Pinheiro, Brasil, Veiga and Buzatto 1986 reported forest biomass inventory in Mogi Guaçu, State of São Paulo. Different models were compared, selecting in each case the best one for estimating total and merchantable stem (to a .13 and .06m top) dry weight without bark, for different species with different ages. The studied especies were: *Pinus elliottii*, *P. oocarpa*, *P. caribaea* var. *hondurensis*, *P.patula*, *P. kesiya*, *P. taeda* and *P. caribaea* var. *caribaea*.

A biomass inventory was accomplished by Brasil et al. 1986 for *Pinus oocarpa* and *P.caribaea* var. *hondurensis*, in ton/hectare, in the State of Minas Gerais. 230 trees were sampled. Total and merchantable dry weights equations (.12, .07 and .03m diameter top) were calculated for each species in each age class. Only the summary was published, but original paper reported the following growth equations, with $W = bo + b1\ D^2H$:

Age	b_i	Total	Merchantable Weight		
(Years)		Weight	.03m	.07m	.12m
P.oocarpa					
7	bo	1.151228	.761514	−1.036191	.002331
	b1	.008650	.008054	.007929	.005809
8	bo	.152338	−.281075	−2.531317	−4.530516
	b1	.010011	.009475	.009446	.008770
10	bo	−2.942078	−3.356981	−6.579636	−13.388714
	b1	.011973	.011533	.011886	.011853
P.caribaea var. *hondurensis*					
7	bo	.472993	.266143	−1.528607	−1.599591
	b1	.008367	.007611	.008208	.007656
8	bo	.223490	−.357635	−2.787895	−6.768035
	b1	.009385	.008999	.009422	.009163
10	bo	−2.140043	−2.471001	−4.577552	−12.227291
	b1	.011493	.011035	.010831	.011233

The author calculated the weight equations that Timoni 1986 utilized for 16 years old *Pinus kesiya* Royle ex Gordon stand, in Itirapina, São Paulo State. Six models were compared, being selected the following ones: a) Total stem wood dry weight: $\ln W = 3.93512 + 2.53822 \ln D + .39349 \ln H$; b) Living bark dry weight:

$W = -.41778 - .02341 D^2 + .00417 D^2H - .00331 DH^2 - .02435 H^2$; c) Dead bark dry weight: $\ln W = -3.26636 + 2.08076 \ln D - .17371 \ln H$; d) Living branches dry weight: $W = 6.32486 - 2.69099 D + .020396 D^2 + .09050 DH - .00760 D^2H$; e) Dead branches dry weight: $W = 7.52306 - 3.68847d + .21274 D^2 + .15818 DH - .00901 D^2H$; f) Needles dry weight: $W = -.29143 - .00705 D^2 + .00260 D^2H - .00175 DH^2 + .00836 H^2$.

REGRESSION MODELS SELECTION

Criteria for choosing the best fit of regression models are discussed by several authors. Following Veiga 1984–b the selection of models should consider not only the multiple regression coefficient r^2, but also the standard error of estimate, the Furnival's index when dealing with logarithmic models, as well as residues uniformity and facility for model application.

Among the models that can be tested for biomass prediction, Veiga 1984–a utilized for volume and weight equations, six models: Spurr's combined variable, australian (Stoat), Naslund, Meyer (Modified), logharithmic combined variable and Schumacher.

A system was elaborated by Veiga, Cataneo and Brasil 1989, where those six models can be compared. Several programmes are integrated in a only system: volume and weight of cutted trees calculus; six regression equations with the selection of the best to estimate weight and/or volume for twelve different variables; estatistical test of those equations; species classification and age; biomass inventory in terms of mass dry weight and wood volume, from the former elements and the measurements of field plots.

MODELS FOR VARIABLE-TOP BIOMASS PREDICTION

Objective of the Research

Most papers published in Brazil related to the utilization of weight equations consider dry weight matter estimates as a function of stem total weight and/or merchantable weight to a unic merchantable top diameter. In a few cases two or three merchantable top diameters are considered.

This fact restricts the generalized utilization of the obtained weight equations, since merchantability limit envolved is frequently different from those utilized for estimatives.

Therefore it would be interesting to find more generalized equations that can be used to estimate dry weight for several merchantable diameter tops and height of trees. That was made, and the main methodology and results are summarized below.

Material and Methods

The present research was developed with *Pinus elliottii* var. *elliottii* (145 trees) and *Pinus caribaea* var. *caribaea* (88 trees), growing in the central region of Sao Paulo State, Brazil.

For both species, trees were sampled considering age and diameter classes. For each tree, necessary measures for volume determination were made. Wood basic density was determined, from discs obtained from each 2.0m sections, utilizing the maximum moisture content method as a function of dry weight and saturated volume. Wood dry matter weight, without bark, were determined for each tree at different heights along the stem.

Models were tested for prediction of merchantable stem dry matter weight (Wm),

without bark, as functions of dbh (D), merchantable top diameter (d) and total stem dry matter weight (Wt).
Models including total stem volume instead of Wt were also studied.

Results and Conclusions

From tested equations for variable-top weight prediction, the best results were obtained from the model:

$$Y = ßo + ß1\ X1 + ß2\ X2$$

where:
Y = ln [1 – (Wm/Wt)]
X1 = ln (d)
X2 = ln (D)

with diameters expressed in cm and weight in kg. This model was adapted from Clutter et al. 1983.

The results obtained for *P. caribaea* var. *caribaea* were the following:

Age (yrs.)	$\hat{ß}o$	$\hat{ß}1$	$\hat{ß}2$	r^2
6	–.426963	1.912132	–1.900600	.8634
11	–.705311	1.269589	–1.346234	.7813
14	.701233	1.877321	–2.340788	.9248
6 – 14	–.070471	1.612856	–1.816346	.8316

and for *P. elliottii* var. *elliottii* the results were:

Age (yrs.)	$\hat{ß}o$	$\hat{\hat{ß}}1$	$\hat{\hat{ß}}2$	$\hat{r}^2$
16 – 17	–.162288	1.837231	–2.150934	.8601
18 – 19	.166374	1.914760	2.135030	.8254
20 – 21	–.451839	1.808910	–1.941590	.8302
22 – 23	.104704	2.094735	–2.341021	.8664
24 – 25	.264179	2.092727	–2.427479	8745
16 – 25	.081120	1.941821	–2.169284	.8467

REFERENCES

Brasil, M.A.M., Veiga, R.A.A. and Coelho, L.C.C. 1980: Produção de madeira seca de *Pinus elliottii. Silvicultura,* São Paulo, 2(16):59.

Brasil, M.A.M., Veiga, R.A.A. and Coelho, L.C.C. 1982: Rendimento em peso de matéria seca de árvores de *Pinus elliottii* Engelm. var. *elliottii. Boletim Técnico do Instituto Florestal,* São Paulo,36(1):1–18.

Brasil, M.A.M., Veiga, R.A.A., Coelho, L.C.C. and Montagna, R.G. 1983: Peso de matéria seca da madeira de 5 espécies do gênero *Pinus* aos 20 anos de idade. *Silvicultura,* São Paulo, 28:739–41.

Brasil, M.A.M., Veiga, R.A.A., Peres, M.C.C. et al. 1986: Biomassa do fuste de plantações comerciais de Pinus da região do Triângulo Mineiro – MG. 5º. *Silvicultura,* São Paulo, 41:171.

Clutter, J.L. et al. 1983: *Timber Management – A Quantitative Approach.* John Wiley, New York. 333p.

Montagna, R.G., Barbosa, O., Brasil, M.A.M., Veiga, R.A.A. and Toledo Filho, D.V.T. 1980: Peso de matéria seca, densidade –8– básica e dimensões de fibras de *Pinus caribaea* Mor. var. *hondurensis* Bar. et Golf. *Silvicultura,* São Paulo, 2(16):57–58.

Montagna, R.G., Barbosa, O., Brasil, M.A.M., Veiga, R.A.A. and Toledo Filho, D.V. 1983: Peso de matéria seca, densidade básica e dimensões de fibras de *Pinus caribaea* Mor. var. *hondurensis* Bar. et Golf. *Silvicultura,* São Paulo, 32:837–840.

Pinheiro, G.S., Brasil, M.A.M., Veiga, R.A.A. and Buzatto, O. 1986: Estimativa do peso de matéria seca em plantios de *Pinus* através de parâmetros dendrométricos. *Boletim Técnico do Instituto Florestal,* São Paulo, 40 (2):135–151.

Timoni, J.L. 1986: Caracterização e quantificação de elementos minerais de um povoamento de *Pinus kesiya* ex Gordon no minicípio de Itirapina (SP.) UNESP, Rio Claro. Thesis. 96p.

Veiga, R.A.A. 1984–a: *Dendrometria e Inventário Florestal.* Fundação de Estudos e Pesquisas Agrícolas e Florestais, Botucatu. 108p.

Veiga, R.A.A. 1984–b: Uso de equações de volume em inventários florestais. *2º Simpósio Sobre Inventário Florestal* , Piracicaba, p.93–102.

Veiga, R.A.A. and Brasil, M.A.M. 1980: Equações para estimativas de peso de matéria seca e de volume para *Eucalyptus propinqua* Deane ex Maiden. *Silvicultura,* São Paulo, 2 (16):136.

Veiga, R.A.A. and Brasil, M.A.M. 1981: Peso de matéria seca e volume de *Eucalyptus propinqua* Deane ex Maiden – equações. *Boletim Técnico do Instituto Florestal,*São Paulo,35(2):73–84.

Veiga, R.A.A., Brasil, M.A.M. and Ferreira, M. 1980: Peso seco do tronco comercial para *Eucalyptus saligna e E.urophylla. Silvicultura,* São Paulo, 2 (16):138.

Veiga, R.A.A., Brasil, M.A.M. and Ferreira, M. 1981: Peso da parte comercial do fuste de *Eucalyptus saligna* e *Eucalyptus urophylla* – estimativa no primeiro corte. *Boletim Técnico do Instituto Florestal,* São Paulo, 35(2):85–92.

Veiga, R.A.A. Brasil, M.A.M., Perez, M.C.C. et al. 1985: Biomass weight inventory of eucalyptus plantations for the production of ethanol in the State of Minas Gerais, Brazil 5th World Forestry Congress, Mexico, 6p.

Veiga, R.A.A., Cataneo, A. and Brasil, M.A.M. 1989: Elaboração de um sistema integrado de computação para quantificação da biomassa florestal. *Científica,* São Paulo, 17(2):231–236.

TWO-STAGE AND THREE-STAGE SAMPLING STRATEGIES TO ESTIMATE AGGREGATE BOLE VOLUME IN THE FOREST

Timothy G. Gregoire
Department of Forestry
Virginia Polytechnic Institute and State University Blacksburg, VA 24061-0324
U.S.A
Harry T. Valentine
U.S.D.A. Forest Service
Durham, NH 03824-0640 U.S A.
George M. Furnival
School of Forestry and Environmental Studies Yale University
New Haven, CT 06511 U.S.A.

ABSTRACT

Two-stage sampling strategies are presented which consist of horizontal point sampling at stage one followed by a second stage of sampling with replacement conducted separately at each point from a list of accumulated heights. Analogous strategies are also presented when the first stage of sampling consists of fixed-area plots. The third stage consists of either importance sampling or control-variate sampling of individual tree stems, which obviates the need to rely on tree volume/biomass equations to ascertain the stem volume or biomass of selected trees. For all two-stage and three-stage strategies, the design-based bias and variance of alternative probability-weighted estimators are derived.

Keywords: modified-point-list sampling, importance sampling, control-variate sampling

INTRODUCTION

The sampling method originated by Bitterlich (1948) and elaborated upon by Grosenbaugh (1952) selects a tree with probability proportional to its basal area. This method is particularly well suited for the task of estimating aggregate bole volume of the forest because of the strong positive correlation between stem basal area and volume. As it is known by a variety of names throughout the world forestry community, we shall refer to it here as horizontal point sampling (HPS).

Point-3P sampling, a two-stage strategy, later was introduced by Grosenbaugh (1971) as a means to sample trees with probability more closely proportional to volume by selecting trees proportional to predicted height in the second (3P) stage. Yandle and White (1977) discussed an alternative two-stage method comprising HPS at stage one and list sampling with replacement at stage two from a list of accumulated heights of trees selected in all first-stage points. With point-3P sampling, the number of trees selected at the second stage is random; with Yandle and White's method the number of second-stage selections is fixed. In neither method does one have control of the distribution of second-stage selections among the points selected at the first stage. Furthermore, Yandle and White's method is only feasible when the current sampling effort is a resurvey of previously visited points from which the list of tree heights had been accumulated.

A modification of Yandle and White's strategy has been the object of recent scrutiny by Wood and Wiant (1992), Schreuder *et al.*(1992), and Gregoire (1992). The modification consists of second-stage selections of trees from a list of tree heights accumulated separately at each point. For the second-stage of sampling, the heights of trees selected on a point presumably would be ocularly measured, and may even be measured in terms of sawlogs or bolts rather than meters. Because the list sampling is conducted independently at each point, the number of trees selected at the second stage at each point can be controlled by the sampler; there need not be a constant number of trees selected at all points. We presume list sampling with replacement at the second stage, in contrast to the list sampling strategy considered by Schreuder *et al* (1992). For sake of exposition we refer to this method as modified-HPS-list sampling.

When the inventory objective is to estimate aggregate bole volume of the forest, some means of ascertaining the bole volume of trees selected in the sample must be used. Grosenbaugh (1964) advocated detailed dendrometery of selected trees so as to compute bole volume directly with negligible measurement error and thereby eliminate bias which could result from the application of an inappropriate volume equation. Commonly, however, only the diameter and height of selected trees are measured, and bole volume is then predicted from a volume equation.

MODIFIED HPS – LIST SAMPLING

Let U_i denote the ith tree in the population, and let Y_i denote the bole volume of U_i. The target parameter is

$$Y = \sum_{i=1}^{N} Y_i \tag{1}$$

where N represents the number of trees in the forest. Let Z_i represent the ascertainable volume of U_i by whatever means of ascertainment is adopted.

In conjunction with the modified-HPS-list sampling method described above, an estimator of Y based on a first-stage sample of k points is

$$\hat{Y} = \frac{A}{k} \sum_{j=1}^{k} \frac{1}{m_j} \sum_{s=1}^{m_j} \sum_{i=1}^{N} \frac{Z_i \dot{H}_j t_{ij} q_{ijs}}{a_i H_i} \tag{2}$$

where

t_{ij} = Bernoulli indicator of inclusion at stage one; $t_{ij} = 1$ if U_i is selected by HPS on the jth point, $t_{ij} = 0$ otherwise;

q_{ijs} = Bernoulli indicator of inclusion at stage two; $q_{ijs} = 1$ if U_i is the sth selection by list sampling at the jth point, $q_{ijs} = 0$ otherwise;

m_j = the number of second-stage selections at the jth point;

H_i = the height of the ith tree in the population in whatever units of measure are used to effect the second stage sampling;

$\dot{H}_j$ = cumulative height of trees selected by HPS at the jth point; $\dot{H}_j = \sum_{i=1}^{N} H_i t_{ij};$

a_i = the inclusion area, in ha, of U_i ; it is that area within the boundaries of the forest where an HPS point can be located which would result in the inclusion of U_i into the first-stage sample;

$a_{ii'}$ = the joint inclusion area, in ha, of U_i and $U_{i'}$; it is that area within the boundaries of the forest where an HPS point can be located which would result in the inclusion of both U_i and $U_{i'}$ into the first-stage sample from a single point location;

A = area of forest, in ha.

It is assumed that when the number of trees selected at the jth point in the first stage of sampling, n_j is zero, the estimator of volume from that point likewise is zero; Yandle and White (1977) adopted the same convention.

Gregoire (1992) shows that $E\left[\dot{H}_j t_{ij} q_{ijs}\right] = \frac{H_i a_i}{A}$. With this result it follows directly that $E\left[\hat{Y}\right] = Z$ and that Bias $\left[\hat{Y}\right] = Z - Y$ where $Z = \sum_{i=1}^{N} Z_i$. When $Z_i = Y_i, \forall U_i, \hat{Y}$ is evidently an unbiased[1] estimator of Y. Gregoire (1992) derived the variance of $\hat{Y}$:

$$\mathrm{Var}\left[\hat{Y}\right] = \sigma_1^2 / k + \sigma_2^2 / k\overline{m} \tag{3}$$

where

$$\sigma_1^2 = A \sum_{i=1}^{N} \frac{Z_i^2}{a_i} - Z^2 + A \sum_{i\neq}^{N} \sum_{i'}^{N} \frac{Z_i Z_{i'} a_{ii'}}{a_i a_{i'}} \tag{4}$$

and

$$\sigma_2^2 = A \sum_{i\neq}^{N} \sum_{i'}^{N} \frac{Z_i a_{ii'}}{a_i H_1} \left(\frac{Z_{i'} H_{i'}}{a_i} - \frac{Z_{i'} H_i}{a_{i'}} \right) \tag{5}$$

and

$$\overline{m} = \left(\frac{1}{k} \sum_{j=1}^{k} \frac{1}{m_j} \right)^{-1} \tag{6}$$

---

[1] Bias is evaluated from the randomization or design-based viewpoint of traditional sample survey theory as discussed in Cochran (1977) and Murthy (1967), as distinct from the model-based viewpoint as discussed by Cassell, Särndal, and Wretman (1977).

RELATED TWO-STAGE STRATEGIES

As indicated earlier, with the modified-HPS-list sampling the inclusion probability of a tree is approximately proportional to its volume. The same effect could be achieved when using fixed area plots at stage one followed by list sampling at stage two, wherein the list at each plot comprises accumulated values, V_i say, of some characteristic that is easy to measure and is approximately proportional to bole volume. This approximate measure could be $V_i = D_i^2 H_i$ for example, or V_i could be a quickly generated prediction from a local volume equation.

In order to accommodate these and other variations of two-stage sampling strategies, we re-express (2) in more general notation as:

$$\hat{Y} = \frac{1}{k} \sum_{j=1}^{k} \frac{1}{m_j} \sum_{s=1}^{m_j} \sum_{i=1}^{N} w_{1i} w_{2ij} Z_i t_{ij} q_{ijs} \tag{7}$$

where w_{1i} is a nonstochastic weight associated with the first stage selection of U_i, and w_{2ij} is a stochastic weight associated with the second-stage selection of U_i on the jth point. Consider the following special cases of $\hat{Y}$ as presented in (7).

Case 1. Modified-HPS-list sampling as described above, namely when ocularly assessed tree heights are accumulated at each point, and Y is estimated by (7) with $w_{1i}= A/a_i$, and $w_{2ij}=$ $w_{2ij} = \dot{H}_j / H_i$ Var $\left[\hat{Y}\right]$ in this Case is as given in (3), with σ_1^2 and σ_2^2 as given in (4), (5), respectively.

Case 2. Same as Case 1 except that $w_{1i}= FA/b_{i,}$ where b_i = basal area of U_i and F is the basal area factor (m²/ha) used in the HPS of the first stage. This estimator admits "boundary bias" owing to the fact that a tree near the boundary of the sampled area, U_i say, will have an inclusion probability $\pi i = a_i/A$ which is smaller than w_{1i}^{-1} Var $\left[\hat{Y}\right]$ in this case as given in (3) with the following redefinitions:

$$\sigma_1^2 = F^2 A \sum_{i=1}^{N} \frac{Z_i^2 a_1}{b_i^2} - \left(F \sum_{i=1}^{N} \frac{Z_i a_i}{b_i} \right)^2 + F^2 A \sum_{i\neq}^{N} \sum_{i'}^{N} \frac{Z_i Z_{i'} a_{ii'}}{b_i b_{i'}} \tag{8}$$

$$\sigma_2^2 = F^2 A \sum_{i\neq}^{N} \sum_{i'}^{N} \frac{Z_i a_{ii'}}{b_i H_i} \left(\frac{Z_i H_{i'}}{b_i} - \frac{Z_i H_i}{b_{i'}} \right) \tag{9}$$

Case 3. Fixed-area-plot sampling at stage one; list sampling with replacement at stage two, where the accumulated total at each plot is $\dot{V}_j = \sum_{i=1}^{N} V_i t_{ij,}$ and where V_i is some convenient proxy for bole volume of U_i. Aggregate volume, Y, is estimated by (7) with $w_{1i}= A/a_i$ and $w_{2ij}= \dot{V}_j / V_{i.}$ Var $\left[\hat{Y}\right]$ in this case is as given in (3) with the following redefinition:

$$\sigma_2^2 = A \sum_{i\neq}^{N} \sum_{i'}^{N} \frac{Z_i a_{ii'}}{a_i V_i} \left(\frac{Z_i V_{i'}}{a_i} - \frac{Z_{i'} V_i}{a_{i'}} \right) \tag{10}$$

and where σ_1^2 is as defined in (4).

Case 4. Same as Case 3 except that $w_{1i}= A/a$, where a is the area (ha) of the fixed-size plot used in the stage one sample. This estimator admits "boundary bias" owing to the fact that a tree closer to the edge than R = $100\sqrt{a/\pi}$ meters will have an inclusion probability $\pi_i = a_i / A$ which is smaller than w_{1i}^{-1}. Var $\left[\hat{Y}\right]$ in this case is as given in (3) with the following redefinitions:

$$\sigma_1^2 = \frac{A}{a^2} \sum_{i=1}^{N} Z_i^2 a_i - \left(\frac{1}{a} \sum_{i=1}^{N} Z_i a_i \right)^2 + \frac{A}{a^2} \sum_{i=}^{N} \sum_{i'}^{N} Z_i Z_{i'} a_i \tag{11}$$

$$\sigma_2^2 = \frac{A}{a^2}\sum_{i\neq}^{N}\sum_{i'}^{N}\frac{Z_i a_{ii'}}{V_i}(Z_i V_{i'} - Z_i V_i) \qquad (12)$$

Regardless of the presence/absence of boundary bias, $\hat{Y}$ will generally be a biased estimator of Y from a design-based standpoint, unless $Z_i = Y_{i,}$ $\forall U_i$,to within negligible measurement error.

A DESIGN-BASED, UNBIASED THREE-STAGE STRATEGY

As an alternative either to extensive dendrometery of U_i in order to ascertain Z_i or as an alternative to the ascertainment of Z_i via prediction by a previously fitted volume equation, we consider extending sampling to a third stage. Horizontal importance sampling (HIS) and horizontal control variate (HCS) sampling have been exposited by Gregoire *et al.*(1987) and Valentine et al.(1992). Both are methods which permit unbiased yet precise estimation of individual stem volume. The third stage of sampling we consider involves the application of HIS or HCS in order to unbiasedly estimate Y_i in the event that U_i is selected in the second stage of sampling. Let Y_i denote the estimator of Y_i so obtained; see Appendix for details. The estimator of Y that we propose is

$$\hat{\hat{Y}} = \frac{1}{k}\sum_{j=i}^{k}\frac{1}{m_j}\sum_{s=1}^{m_j}\sum_{i=1}^{N} w_{1i} w_{2ij} \breve{Y}_i t_{ij} q_{ij} \qquad (13)$$

Because $E\left[\breve{Y}_i\right] = Y_i$, it follows directly that $E\left[\hat{\hat{Y}}\right] = Y$, thereby establishing the unbiasedness of $\hat{\hat{Y}}$ as an estimator of Y.

Case 1': Same as Case 1 for stages one and two, and $w_{1i} = A/a_i$, $w2_{ij} = \dot{H}_j / H_i$ as in Case 1. The variance of $\hat{\hat{Y}}$, which is derived in the Appendix, is

$$\text{Var}\left[\hat{\hat{Y}}\right] = \frac{\sigma_1^2}{k} + \frac{\sigma_2^2}{k\overline{m}} + \frac{\sigma_3^2}{k\overline{m}_q} \qquad (14)$$

where

$$\sigma_3^2 = A\sum_{i=1}^{N}\frac{\text{Var}\left[\breve{Y}_i\right]}{a_i H_i}\left(H_i + \sum_{i\neq i'}^{N}\frac{H_{i'} a_{ii'}}{a_i}\right) \qquad (15)$$

$$\overline{m}_q = \left(\frac{1}{k}\sum_{j=i}^{k}\frac{1}{m_j^2}\right)^{-1}$$

and where $\text{Var}\left[\breve{Y}_i\right]$ is the variance of $\breve{Y}_i$ based on a HIS (or HCS) sample of size c_i; and where σ_1^2 and σ_2^2 are as defined in (4), (5), respectively (see Appendix).

Case 2': Same as Case 2 for stages one and two, and $w_{1i} = FA/b_i$, $w2_{ij} = \dot{H}_j / H_i$ as in Case 2, also. The variance of $\hat{\hat{Y}}$ is as given in (14) with σ_1^2 as defined in (8), σ_2^2 as defined in (9), and

$$\sigma_3^2 = F^2 A \sum_{i=1}^{N} \frac{\mathrm{Var}\left[\breve{Y}_i\right]}{b_1^2 H_i} \left(H_i a_i + \sum_{i \neq i'}^{N} H_{i'} a_{ii'} \right) \tag{16}$$

Case 3': Same as Case 3 for stages one and two, and $w_{1i} = A/a_i$, $w_{2ij} = \dot{V}_j / V_i$ as in Case 3, also. The variance of $\hat{\hat{Y}}$ is as given in (14) with σ_1^2 as defined in (4), σ_2^2 as defined in (10), and

$$\sigma_3^2 = A \sum_{i=1}^{N} \frac{\mathrm{Var}\left[\breve{Y}_i\right]}{a_i V_i} \left(V_i + \sum_{i \neq i'}^{N} \frac{V_{i'} a_{ii'}}{a_i} \right) \tag{17}$$

Case 4': Same as Case 4 for stages one and two, and $w_{1i} = A/a$, $w_{2ij} = \dot{V}_j / V_i$ as in Case 4, also. The variance of $\hat{\hat{Y}}$ is as given in (14) with σ_1^2 as defined in (11), σ_2^2 as defined in (12), and

$$\sigma_3^2 = A \sum_{i=1}^{N} \frac{\mathrm{Var}\left[\breve{Y}_i\right]}{a^2 V_i} \left(V_i a_i + \sum_{i \neq i'}^{N} V_{i'} a_{ii'} \right) \tag{18}$$

UNBIASED ESTIMATOR OF VARIANCE

In all four two-stage cases an unbiased estimator of Var $\left[\hat{Y}\right]$ is

$$\mathrm{var}\left[\hat{Y}\right] = \frac{\sum_{j=i}^{k} \left(\hat{Y}_j - \hat{Y} \right)^2}{k(k-1)} \tag{19}$$

where $\hat{Y}_j$ is the estimator of Y provided by the two-stage sample on the jth point only. A proof of the unbiasedness of (19) as an estimator of Var $\left[\hat{Y}\right]$ is given in Gregoire (1992).
In all four three-stage cases an unbiased estimator of Var $\left[\hat{\hat{Y}}\right]$ is

$$\mathrm{var}\left[\hat{\hat{Y}}\right] = \frac{\sum_{j=1}^{k}\left(\hat{\hat{Y}}_j - \hat{\hat{Y}}\right)^2}{k(k-1)} \tag{20}$$

where $\hat{\hat{Y}}_j$ is the estimator of Y provided by the three-stage sample on the jth point only. A proof of the unbiasedness of (20) an an estimator of Var $\left[\hat{\hat{Y}}\right]$ is given in the Appendix.

REFERENCES

Bitterlich, W. 1948: Die Winkelzahlprobe. Allgem. Forst-u, Holzw. Ztg. 59 (1/2):4–5.

Bitterlich, W. 1984: The Relascope Idea: Relative Measurements in Forestry. Commonwealth Agricultural Bureaux: Slough, England.

Cochran, W. G. 1977: Sampling Techniques. Wiley: New York. 428 p.

Gregoire, T. G., H. T. Valentine, and G. M. Furnival. 1987: Sampling methods for tree volume and volume increment. *Forest Ecology and Management* vol. 21, pp. 311–323.

Gregoire, T. G. 1992: Analytical derivation of the variance of the modified point-list sampling estimator. In: Proc. of IUFRO. conf. Integrating Forest Information Over Space and Time (B. Turner and G. Wood, eds.), Canberra, Australia. pp. 404–415.

Grosenbaugh, L. R. 1952: Plotless timber estimates – new, fast easy. *Journal of Forestry* vol. 50, pp. 32–37.

Grosenbaugh, L. R. 1964: Some suggestions for better sample-tree-measurments. Society of American Foresters (1963, Boston, Mass., U.S.A.) Proc: 36–42.

Grosenbaugh, L. R. 1971: STX 1–11–71 for dendrometry of multistage 3P samples. S. D. A. Forest Service Publ. FS-277. 63 pp.

Murthy, M. N. 1967: Sampling: Theory and Methods. Statistical Publ. Soc.: Calcutta, India

Rubinstein, R. Y. 1981: Simulation and the Monte Carlo Method. Wiley: New York. 78 p.

Schreuder, H. T., Z. Ouyang, M. Williams. 1992: Point-Poisson, point-pps, and modified point-pps sampling: efficiency and variance estimation. *Canadian Journal of Forest Research* (In press)

Valentine, H. T., C. Bealle, and T. G. Gregoire. 1992: Comparing vertical and horizontal modes of importance and control-variate sampling for bole volume. *Forest Science* vol. 38, no. 1, pp. 160–172.

Wood, G. B. and H. V. Wiant, Jr. 1992: Comparison of point-3P and modified point-pps sampling for inventory of mature native hardwood forest in SE New South Wales. *Canadian Journal of Forest Research* vol. 22, pp. 725–728.

Yandle, D. O. and F. M. White. 1977: An application of two-stage forest sampling. *Southern Journal of Applied Forestry,* vol. 1, no. 3, pp. 27–32.

APPENDIX

A: HIS and HCS Estimators

Both HIS and HCS are probability sampling methods which can be used to unbiasedly estimate an integral. Their relevance to forestry is that many characteristics of an individual tree can be regarded as an integral, for example bole volume is the integral of the cross-sectional area of the bole between two heights. In the context of the three-stage sampling strategies presented earlier, suppose that U_i has been selected into the sample at the second stage, and that the remaining task is to estimate its bole volume, Y_i at the third stage. More specifically, let the target parameter in the third stage be $Y_i = V_i\,(H_L, H_U)$, where

$$V_i(H_L,H_U)=\int_{H_L}^{H_U} A_i(h)\partial(h) \tag{A1}$$

where

H_L= lower height of the section of interest on the bole

H_U= upper height of the section of interest on the bole

$A_i(h)$ = the cross-sectional area of the bole at height h, $H_L \le h \le H_U$

Both HIS and HCS rely on a bole taper function which relates cross-sectional area of the bole to vertical position on the bole. We call this taper function a proxy function because it may be integrated to yield a proxy measure of V_i (H_L, H_U), namely

$$V_{p,i}(H_L,H_U)=\int_{H_L}^{H_U} A_{p,i}(h)\partial(h) \tag{A2}$$

where $A_{p,i}(h)$= the cross-sectional area of the bole as predicted by the proxy function at height h, $H_L \le h \le H_U$.

The HIS estimator of V_i (H_L, H_U) can be regarded as a multiplicative adjustment of $V_{p,i(}(H_L,$ $H_U)$, whereas HCS can be regarded as an additive adjustment. The design-unbiasedness of neither estimator depends on how well or poorly $A_{p,i}(h)$ describes the true cross-sectional area $A_i(h)$, however the precision of both estimators improves the more closely the proxy function mimics the actual cross-sectional area taper of the bole.

Let c_i denote the size of the HIS or HCS on U_i. Let $f_i(h) = A_{p,1}(h)/V_{p,i}(h_L, H_U)$ for $H_L \le h \le H_U$, and $f_i(h) = 0$, elsewhere. The HIS estimator of $Y_i = V_i(H_L, H_U)$ is $\check{Y}_i = \hat{V}_i(H_L,H_U)$, where

$$\hat{V}_i(H_L,H_U)=\frac{1}{c_i}\sum_{r=1}^{c_i}\frac{A_i(\theta_{ir})}{f_i(\theta_{ir})}$$

$$=\frac{V_{p,i}(H_L,H_U)}{c_i}\sum_{r=1}^{c_i}\frac{A_i(\theta_{ir})}{f_i(\theta_{ir})}$$

where h = θ_{ir} is the r^th^ height on the bole at which $A_i(h)$ is measured and $A_{p,1},(h)$ is evaluated. The points of measurement, θ_{ir}, r=1,..., c_i, are determined as the solutions to

$$u_r \int_{H_L}^{\theta_{ir}} f_i(h)\partial(h) = \int_{H_L}^{\theta_{ir}} \frac{A_{p,i}(h)}{V_{p,i}(H_L,H_U} \partial h$$

where $u_r \sim U[0,1]$ See Rubinstein (1981) for a general statistical treatment of importance sampling and its optimal properties, and see Valentine *et al.* (1992) for an extended discussion of its application in order to estimate bole volume.

Let $t_i(h) = [H_U - H_L]^{-1}$. A HCS estimator of $Y_i = V_i(H_L,H_U)$ is $\breve{Y}_i = \hat{V}_i(H_L,H_U)$, where

$$\hat{V}_i(H_L,H_U) = V_{p,i}(H_L,H_U) + \frac{1}{c_i}\sum_{r=1}^{c_i} \frac{D_i(\theta_{ir})}{t_i(\theta_{ir})}$$

$$= V_{p,i}(H_L,H_U) + \frac{H_U - H_L}{c_i}\sum_{r=1}^{c_i} D_i(\theta_{ir})$$

where $D_i(h)=A_i(h)-A_{p,i}(h)$, and where $\theta_{ir} \approx U[H_L,H_U], r = 1,\ldots,C_i$.

From Gregoire *et al.* (1987) we obtain the variance of $\breve{Y}_i$ when $\breve{Y}_i$ represents the HIS estimator of Y_i *viz.*

$$\mathrm{Var}\left[\breve{Y}_i\right] = \frac{1}{c_i}\left(\int_{H_L}^{H_U} \frac{A_i^2(h)}{f_i(h)}\partial h - Y_i^2\right);$$

and when $\breve{Y}_i$ represents the HCS estimator of Y_i

$$\mathrm{Var}\left[\breve{Y}_i\right] = \frac{1}{c_i}\left(\int_{H_L}^{H_U} \frac{D_i^2(h)}{t_i(h)}\partial h - D_i^2\right)$$

B: Derivation of Var $\left[\hat{\hat{Y}}\right]$ in Case 1´

In the following derivation we use the shorthand notation to denote conditional expectation and variance that appears in conventional sampling texts such as Murthy (1967, p. 42) and Cochran (1977, p. 275). Namely for three-stage sampling, $E_1[\bullet]$ denotes the probability-weighted mean of all possible first-stage selections, i.e., the design-based expected value over the first stage of randomization; $E_2[\bullet]$ denotes the mean over all second stage selections that are possible under a fixed first stage sample; $E_3[\bullet]$ is the conditional expected value given a particular sample selection in the prior two stages. $\mathrm{Var}_j[\bullet]$ is similarly defined for the variance at the j^th^ stage, j=1,2,3.

These preliminary results will be needed:

(i)$E_3\left[\hat{\hat{Y}}\right] = \hat{Y}$, because both HIS and HCS unbiasedly estimate Y_i if U_i is selected;

(ii)$\mathrm{Var}\left[\hat{Y}\right] = \mathrm{var}_1\left[E_2\left[\hat{Y}\right]\right] + E_1\left[\mathrm{Var}_2\left[\hat{Y}\right]\right]$

(iii)$E_1\left[E_2\left[t_{ij}q_{ijs}\dot{H}_j^2\right]\right] = \frac{H_i^2 a_i}{A} + \sum_{i \neq i'}^{N} \frac{H_i H_{i'} a_{ii'}}{A}$
from Gregoire (1992)

Using conditional expectations and variances,

$$\mathrm{Var}\left[\hat{\hat{Y}}\right]=\mathrm{Var}_1\left[E_2\left[E_3\left[\hat{\hat{Y}}\right]\right]\right]+E_1\left[\mathrm{Var}_2\left[E_3\left[\hat{\hat{Y}}\right]\right]\right]+E_1\left[E_2\left[\mathrm{Var}_3\left[\hat{\hat{Y}}\right]\right]\right]$$

$$=\mathrm{Var}_1\left[E_2\left[\hat{Y}\right]\right]+E_1\left[\mathrm{Var}_2\left[\hat{Y}\right]\right]+E_1\left[E_2\left[\mathrm{Var}_3\left[\hat{\hat{Y}}\right]\right]\right]\text{, from (i) above,}$$

$$=\mathrm{Var}\left[\hat{Y}\right]+E_1\left[E_2\left[\mathrm{Var}_3\left[\hat{\hat{Y}}\right]\right]\right]\text{ ,from (ii) above,} \qquad \text{(B1)}$$

Now,

$$\mathrm{Var}_3\left[\hat{\hat{Y}}\right]=\frac{A^2}{k^2}\sum_{j=i}^{k}\frac{1}{m_j^2}\sum_{s=1}^{m_j}\sum_{i=1}^{N}\mathrm{Var}\left[\breve{Y}_i\right]\left(\frac{t_{ij}q_{ijs}\dot{H}_j}{a_iH_i}\right)^2$$

$$=\frac{A^2}{k^2}\sum_{j=1}^{k}\frac{1}{m^2}\sum_{s=1}^{m_j}\sum_{i=1}^{N}\frac{\mathrm{Var}\left[\breve{Y}_1\right]}{a_i^2H_i^2}\left(t_{ij}q_{ijs}\dot{H}_j^2\right)$$

Thus,

$$E_1\left[E_2\left[\mathrm{Var}_3\left[\hat{\hat{Y}}\right]\right]\right]=\frac{A^2}{k^2}\sum_{j=1}^{k}\frac{1}{m_j^2}\sum_{s=1}^{m_j}\sum_{i=1}^{N}\frac{\mathrm{Var}\left[\breve{Y}_i\right]}{a_i^2H_i^2}E_1\left[E_2\left[t_{ij}q_{ijs}\dot{H}_j^2\right]\right]$$

$$=\frac{A^2}{k^2}\sum_{j=1}^{k}\frac{1}{m_j^2}\sum_{s=1}^{m_j}\sum_{i=1}^{N}\frac{\mathrm{Var}\left[\breve{Y}_i\right]}{a_i^2H_i^2}\left(\frac{H_i^2a_i}{A}+\sum_{i\neq i'}^{N}\frac{H_iH_{i'}a_{ii'}}{A}\right)$$

$$=\frac{A}{k^2}\sum_{j=1}^{k}\frac{1}{m_j^2}\sum_{s=1}^{m_j}\sum_{i=1}^{N}\frac{\mathrm{Var}\left[\breve{Y}_i\right]}{a_iH_i}\left(H_i+\sum_{i\neq i'}^{N}\frac{H_{i'}a_{ii'}}{a_i}\right)$$

$$=\frac{1}{k\overline{m}}\sigma_3^2$$

where

$$\overline{m}_q=\left(\frac{1}{k}\sum_{j=1}^{k}\frac{1}{m_j^2}\right)^{-1} \quad\text{and}\quad \sigma_3^2=A\sum_{i=1}^{N}\frac{\mathrm{Var}\left[\breve{Y}_i\right]}{a_iH_i}\left(H_i+\sum_{i\neq i'}^{N}\frac{H_{i'}a_{ii'}}{a_i}\right)$$

Combining this result with (B1) yields

$$\mathrm{Var}\left[\hat{\hat{Y}}\right]=\frac{\sigma_1^2}{k}+\frac{\sigma_2^2}{k\overline{m}}+\frac{\sigma_3^2}{k\overline{m}_q}$$

where σ_1^2, σ_2^2, and $\overline{m}$ are as defined in (4)–(6), and where k denotes the number of points (plots) used in the first stage of sampling.

C: Unbiased estimator of $\mathrm{Var}\left[\hat{\hat{Y}}\right]$

Let $\mathrm{var}\left[\hat{\hat{Y}}\right]=\dfrac{\sum_{j=1}^{k}\left(\hat{\hat{Y}}_j-\hat{\hat{Y}}\right)^2}{k(k-1)}$ where $\hat{\hat{Y}}_j=\dfrac{1}{m_j}\sum_{s=1}^{m_j}\sum_{i=1}^{N} w_{1i}w_{2ij}\breve{Y}_i t_{ij}q_{ijs}$.

Claim: $E\left[\mathrm{var}\left[\hat{\hat{Y}}\right]\right]=\mathrm{Var}\left[\hat{\hat{Y}}\right]$.

Proof: Re-express var $\left[\hat{\hat{Y}}\right]$ as var $\left[\hat{\hat{Y}}\right]=\dfrac{\frac{1}{k}\sum_{j=1}^{k}\hat{\hat{Y}}_j^2-\hat{\hat{Y}}^2}{k-1}$ and re-express $E\left[\hat{\hat{Y}}^2\right]$ as

$E\left[\hat{\hat{Y}}^2\right]=\dfrac{1}{k^2}\sum_{j=1}^{k}E\left[\hat{\hat{Y}}_j^2\right]+\dfrac{k-1}{k}\left(E\left[\hat{\hat{Y}}\right]\right)^2$. Then taking the expected value of the former and substituting for $\sum_{j=1}^{k}E\left[\hat{\hat{Y}}_j^2\right]$ yields

$$E\left[\mathrm{var}\left[\hat{Y}\right]\right]=\frac{\frac{1}{k}\sum_{j=1}^{k}E\left[\hat{\hat{Y}}_j^2\right]-E\left[\hat{\hat{Y}}^2\right]}{k-1}$$

$$=\frac{\frac{1}{k}\left(k^2E\left[\hat{\hat{Y}}^2\right]-k(k-1)\left(E\left[\hat{\hat{Y}}\right]\right)^2\right)-E\left[\hat{\hat{Y}}^2\right]}{k-1}$$

$$=\frac{(k-1)E\left[\hat{\hat{Y}}^2\right]-(k-1)\left(E\left[\hat{\hat{Y}}\right]\right)^2}{k-1}$$

$$=E\left[\hat{\hat{Y}}^2\right]-\left(E\left[\hat{\hat{Y}}\right]\right)^2$$

$\mathrm{Var}\left[\hat{\hat{Y}}\right]$, by definition.

THE USE OF A LANDSCAPE CONCEPT AS A BASIS FOR FOREST MANAGEMENT

Andrei Gromtsev & Vladimir Golubev
Head of the Laboratory for Forest Ladscape Ecology
Forest Research Institute, Karelian Research Center,
Russian Academy of Science
and
Engineer, Karelian Forest Management Enterprise

ABSTRACT

The present-day concept, which provides a basis for inventory of forest areas, should be improved. The use of a landscape approach seems to be promising for the conceptual development of forest management. It is advisable to elaborate a system of forest management categories in keeping with the natural (Landscape) features of forest cover organization.

Keywords: forest landscape, interecosystem relations, forest management concept.

INTRODUCTION

There must be a certain concept to provide a basis for inventory of forest areas. The present knowledge of forest ecology and geography allows us to critically discuss the existing forest management system and to propose some ways of its improvement. It is not the goal of the present paper to propose a comprehensive programme of resolving this problem. The authors meant to outline a trend for conceptual development of forest management which, in their opinion, is most promising and meets the dimensions of running a multi-resource (multi-purpose) forest economy.

METHODS

The basis for the study was provided by the classification, map, and comprehensive characterization of Karelian forest landscapes made by a research team headed by A.D. Volkov. Relevant terminology, theoretical approaches as well as the principles and methods used for the comprehensive study of forest landscapes have been discussed in detail elsewhere (Volkov et al. 1981, 1990 and others). We understand landscape as a genetically homogeneous territory on which land forms, Quaternary deposits, hydrological, soil, and microclimatic conditions as well as forest phytocenoses and faunistic complexes alternate equally. The basis for this definition is provided by a concept of geographic landscape (Solnzev 1948 and others). In our study, types of landscape were differentiated in terms of genetic types of relief and Quaternary deposits, the degree of paludification and predominant primeval forests. Thus, 18 types of landscape are recognized in the mid-taiga subzone where the structure as well as the spontaneous and anthropogenic dynamics of forest cover were investigated. This study was conducted together with geobotanical and mire investigations. Studies are now in progress in the north taiga subzone of Karelia.

The biogeocenotic structure of forests (biogeocenosis (BGC) type spectrum and the areal arrangement of BGC), interecosystem relations, the productivity of BGC, the scope and regularities of anthropogenic forest cover transformation, including forest cover transformation, including forest plant succession, fire regime in spontaneous forests and other problems were studied. A variety of methods and techniques based on the instructions provided by Sukachev and Zonn (1961) have been used. The methods employed in these investigations have been described in detail elsewhere (Volkov et al. 1990 etc.).

RESULTS

In this part of the paper, the results of the above studies are briefly described. First of all, they are theoretically generalized with the view to improve a general concept of forest inventory.

It has been found that within a forest vegetation (climatic) zone, the structure as well as the spontaneous and anthropogenic dynamics of forest cover are dependent on the landscape of a region. This is primarily true of the least dynamic combination of hydrological, soil, and microclimatic conditions within an area homogeneous in the genesis and combination of land forms as well as the composition of Quaternary deposits. As the result of primary successions, a certain spectrum and areal arrangement of elementary forest ecosystems (BGC), transformed in the course of secondary (anthropogenic etc.) successions, developed in the landscape. Elementary forest communities interact by means of interecosystem relations to form bigger areal-functional clusters (ecosystems). At least three types of relations are used:

1) Direct (transit etc.) relations (seed exchange between forest communities and matter via soil runoff, hydrographic network etc.);
2) Direct peripheral interaction (ecotonic zone dynamics in the course of mire formation etc.);
3) Interdependence maintained through joint regulation of some natural processes and phenomena (some characteristics of fire regime and microclimatic conditions that depend on the areal arrangement of forest ecosystems etc.)

A definite pattern of serial forest communities in landscape corresponds to that of primary BGC fully reflecting the structure of forest habitats. By that we mean a landscape complex of succession series. As a whole, a forest-forming process in the landscape seems to be autonomous, unless the processes related to plant distribution as well as global climatic changes are taken into account. Forest cover is structured at two levels in the landscape. BGC within a geographic facies is a lowest-rank forest ecosystem. BGC-complexes, which are mainly in direct contact with each other in the forms of mesorelief, represent the next (higher) level in the organization of ecosystems known as urotshistshe. An alternation of urotshistshe within a territory, homogeneous in the genesis of relief and a combination of its forms as well as soil, hydrological and other conditions, forms a landscape. Furthermore, there exist intermediate units referred to as podurotshistshe and terrane. This harmonious system of topological units differentiated in landscape science adequately reflects also the structural-functional organization of forest cover as a major biotic component of taiga landscape. In other words, such a hierarchy of forest ecosystems built according to the present-day geoecological concept of natural system organization seems to be not only a universal tool for understanding taiga forests, but also a single basis for their inventory and optimum utilization.

In Russia, forest management is conventionally based on subdivision of forests into individual lots that are mainly uniform in pytocenotic characteristics. Lots, similar in this respect, are combined to form a forest type. It is within these areally separated wood lots that forest resources are revealed and assessed and recommendations for their optimum utilization are given. Various economic categories of forests (parts, sections) are differentiated, and a certain forestry regime with a certain priority is set up in each. The amount of cutting is calculated from a ratio between the area of stands and the growing stock of different age classes for individual economic forest categories. However, the problem is that many phenomena and processes observed in the forest cover are not determined only by the properties of individual, areally separated wood lots, let alone their economic groups. Such subdivision of areally and functionally integral forest ecosystems of superbiogeocenotic level actually makes it impossible to comprehensively characterize them ecologically to elaborate an ecologically and economically optimum approach to forest utilization. It is thus possible to reveal and estimate wood stock within individual homogeneous, but areally separated wood lots collectively defined as a forest type. It is necessary to know the position of a given ecosystem in the general "natural framework" of forest cover in one or other area.

On the other hand, forest management is the only organization which conducts complete detailed inventory of forest cover. However, the concept on which it is based is fairly narrow and is oriented at a forest utilization project with regard to growing stock. Nevertheless, we think that forest management could include activities aiming at inventory of natural-areal forest complexes differing in taxonomic level. The main goal of this work is to reveal and evaluate various forest resources and to present recommendations for their optimum utilization that can be applied to organizing multi-purpose (multi-resource) forest economy as a basis for regional utilization of terrestrial ecosystems in taiga zone.

We presume that the system of forest management categories used in forest inventory should be brought in correspondence with natural forest cover organization. It must be a hierarchical system of accounting (economic) units. Accounting and evaluation should be made and economic recommendations must be presented at every level with regard to the resource or quality of forest ecosystem which is most strictly determined at this level. In this connection, the following approach seems appropriate. It is advisable to differentiate objects of forest management and forestry on the basis of available data on zonal (climatic indices) and azonal (macrorelief etc.) physicogeographic demarcation. Thus, the Baltic Shield region is prominent under the conditions existing in the European part of the taiga zone. It has a unique combination of natural conditions related to the proximity and exposure of the crystalline basement. This regional-level macrosystem is clearly differentiated climatically into a series of zones and subzones alternating from north to south: arctic deserts and tundra, forest-tundra, northern-, middle-, and southern taiga. Within a subzone, the structural-dynamic organization of ecosystems depends on azonal landscape conditions, primarily the geomorphological characteristics of an area. Within landscape, forest ecosystems are differentiated at two major taxonomic levels: facies (BGC) and urotshistshe (BGC complex on the forms of mesorelief).

It is advisable to bring the forest management and multi-purpose (multi-resource) forestry system in conformity with the natural organization of forest systems described above. Economic measures should be developed and applied to the forest ecosystem qualities that are most strictly determined at this forest community level. In other words, the system of forest management and economic categories must be adequate to natural forest ecosystem organization.

In this connection, the following example is appropriate. All problems related to estimation of growing stock and planning some forestry measures (the proportion of selection in selective cutting, the advisability and methods of clear cutting etc.) can be resolved at BGC (facies) level. These are the forest cover qualities that are dependent on the conditions existing in this habitat or in a certain stand such as the age and mixing pattern of forest-forming species etc. At the forest urotshistshe level, for example, it is reasonable to characterize and assess a natural reforestation process after cutting and to elaborate forest regeneration measures. This is related to the fact that this process is not only determined by BGC (facies) level. At urotshistshe level, it wholly depends on the specifity of forest growth conditions in its constituent BGC, a system of interbiogeocenotic seed exchange, a natural fire regime, microclimatic conditions etc.

At the next, higher taxonomic (landscape) level of natural systems, it is advisable to reveal and evaluate ecological, recreational and other forest resources and quality and to outline a series of economic measures, landscape being represented as a regional-level ecosystem. It is then necessary utilization trend, e.g. a source of raw materials, recreation, environmental protection, preservation of nature or an optimum combination of these options.

Once the principal trend is specified, it is possible to outline a system of economic measures to be taken to use and reproduce the principal type of resource or a group of resources. This implies recreational, raw-material, protective or combined multi-resource forestry. Therefore, a perfect integral object of forest management and forestry is forest landscape the boundaries of which coincide with a forest district or its economic part. Furthermore, the use of structural landscape units as a basis for forest management markedly increases the homogeneity of taxation sites (Kireyev 1977 and others), the reliability and longevity of forecasts relative to forest ecosystems etc.

It is possible, for example, to plan the strategy of multi-purpose (multi-resource) forest economy at the forest macroecosystem (e.g. forest subzones on the Baltic Shield) level. The strategy could include general principles and methods of running forest economy with regard to the natural characteristics of the region as well as its position and role in the natural organization and stable functioning of global-level ecosystems.

CONCLUSION

It can be argued from the results of forest studies conducted on the basis of landscape and biogeocenoses that a geoecological (landscape) concept of natural ecosystem organization can be used in forest management. This concept reflects the general principles and characteristics of natural forest cover organization that must provide a conceptual basis for inventory of forest ecosystems. So far, the lowest-rank concepts and categories of ecosystems have been used in present-day forest management. Ideally, a system of forest management and forestry units and categories must be adequate to natural forest cover organization.

REFERENCES

Volkov A.D., Jerukov G.V., Karavajev V.N., Lak G.U., 1981:Lesnye landsafty Karelskoi ASSR. *Priroda i hozjaistvo Severa,* Murmansk, No. 9, pp.10–17.

Volkov A.D., Gromtsev A.N., Jerukov G.V. et al., 1990:Ekosistemy landsaftov zapada srednei taigi (struktura, dinamika). Karelian Research Center, Russian Academy of Science, Petrozavodsk, pp.284.

Kireyev D.M., 1976: Metody izucenija lesov po aerofotosnimkam. Nauka, Novosibirsk, pp. 216.

Solnzev N.A., 1948: Prirodnij landsaft i nekotorie jego obsciezakonomernosti. Trudy II Vsesojuznogo geograficeskogo s''ezda, Vol. 2, Moscow, pp.258–269.

Sukachev V.N., Zonn S.V.,1961: Metodiceskie ukazanija k izuceniju tipov lesa, Moscow, pp.143.

A MODEL BASED METHOD FOR ESTIMATING THE PARAMETERS OF SYSTEMATIC CLUSTER SAMPLING

A Kangas
Joensuu University, Faculty of Forestry
Joensuu, Finland

ABSTRACT

This paper is a study of model based estimators of mean and standard error for volume, for the Finnish National Forest Inventory. Estimators used are based on different assumptions about the covariance structure of sampling errors. Model based estimators are compared to classical estimators. The classical estimator of standard error is obtained with the aid of quadratic forms. The model based estimators and covariance models give results quite similar to the quadratic forms.

INTRODUCTION

The National Forest Inventory of Finland has always been based on systematic design. Systematic cluster designs have been used since the 1960's. The most difficult thing in systematic sampling designs, with respect to classical sampling theory, is that no general estimators of sampling errors can be found (Ripley, 1981).

The problem can be presented by the concepts of stochastic processes (Ranneby, 1981a). The population is assumed to be a realization of a homogeneous stochastic process Z(x) with $E(Z(x))=\mu$ and $\mathrm{var}(Z(x))=s^2$. If the process is isotropic and stationary the covariances $c(x_1,x_2)$ between variables at two points depend only on distance between plots. The mean value in area Q is

$$\overline{Z}(Q)=\frac{1}{|Q|}\int_Q Z(x)dx \tag{1}$$

where
$|Q|$ is the area of Q.

Measurements are made at sample plots, which are centered at points labeled by u. The error variance of mean can be presented as (Ripley, 1981)

$$\mathrm{var}(\hat{Z}-\overline{Z})=\frac{1}{n^2}\sum_{u,v}C(u,v)-2\sum_{u}\frac{1}{|Q|n}\int_Q C(u,x_2)dx_2+\frac{1}{|Q|^2}\int_Q\int_Q C(x_1,x_2)dx_1dx_2 \tag{2}$$

where
n is the number of measurement points.

This formula has not been used in estimating the standard error of mean, because, in a systematic sample design, the plots form an r x s grid, and there is no information on the covariance in distances shorter than the grid size (Ripley, 1981). If the method is a systematic cluster sampling, the covariances in short distances can be estimated from information within the cluster. Correlation functions for systematic cluster sampling have been estimated (Korhonen & Maltamo, 1991; Ranneby, 1981b) but they have been used for comparing the shapes and sizes of tracts, not for estimating the standard error on larger areas.

Nevertheless, there can be found many formulas proposed for estimating the standard error of systematic sampling. The formulas for plot surveys were first investigated in Matérn (1947, 1960) and later in Ranneby (1981a). Usually special quadratic forms in the observations are used.

In this paper the model based method for estimating the mean and standard error for systematic cluster sampling is presented. Different model based estimators of mean and standard error of mean are compared with the classical estimators, and with empirical studies. The classical estimator for standard error is obtained by quadratic forms.

The material used in the calculations is from the VIII national forest inventory of Finland, from the forestry board district of Pirkka-Häme. The sample plots were measured in 1986–1987. The material consists of 227 clusters (tracts) and 3668 sample plots, 3010 of which are on forest land. The shape of the tract is a half-square. The distance between tracts is 8 km, and the distance between sample plots within the tracts is 200 m. For each sample plot the volume per hectare was calculated using height and volume models. In sample tree plots, the height is known, and in the tally tree plots it is estimated using models.

ESTIMATORS OF MEAN AND STANDARD ERROR

The population mean for systematic sample design is estimated simply by sample mean as in simple random sampling. For standard error there are no general estimators to be found. A number of different methods for estimating the standard error of systematic sampling have been proposed. Those of them, that have proved to be useful in practice, are based on quadratic forms, or on spatial smoothing of interesting variables (Matérn, 1947). The standard error of mean volume (on forest land) in Finnish NFI is estimated with the quadratic form (Päivinen, 1987; see also Salminen, 1973)

$$\operatorname{var}(\hat{y}) = \frac{q\sum_{i=1}^{m} T_i}{n^2} \tag{3}$$

where
n = total number of sample plots
m = total number of tract groups
q = number of tracts each tract group represents
and

$$T_i = \frac{1}{4}(Z_{i1} - Z_{i2} - Z_{i3} + Z_{i4})^2 \tag{4}$$

In order to be able to calculate the standard error of ratio estimate (mean volume on forest land area), the ratio is linearized with Taylor series expansion (Ranneby, 1981a). The linearized form of ratio is

$$Z_{ij} = (y_j - y)n_j, \quad j=1,2,3,4 \tag{5}$$

where
y_j = mean volume on forest land in cluster j (tract j)
y = sample mean volume on the area
n_j = number of sample plots on forest land in the tract j
the other notations as above.

Usually the tract groups are formed so that each tract belongs to four groups, and the value of q is one. (Fig 1). In this quadratic form, the z_j-values are not compared to the general mean, but to the values from nearby tracts. In this way, the effect of linear trend in the population can be taken into account (Päivinen, 1987).

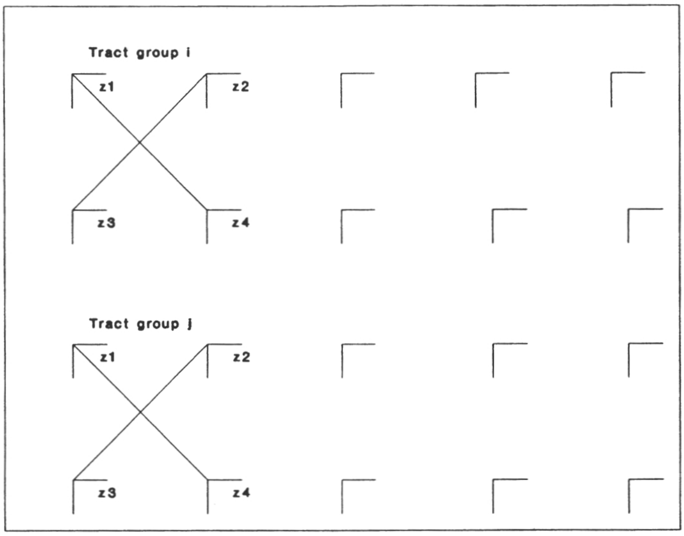


Fig. 1. Formation of tract groups for calculation of standard error

Using the superpopulation models, the problem can be generally presented by two different types of models. The first type is a model where no additional variables are incorporated. The model is (e.g. Kangas, 1991)

$$y_i = \mu + \varepsilon_1 \tag{6}$$

In this case the predictor of the population mean is

$$\bar{\mu} = (D'\Sigma^{-1}D)^{-1}D'\Sigma^{-1}Y \tag{7}$$

where
D is the design vector that consists of ones and
Σ is the variance-covariance matrix of ε.

and the estimator of the error variance is

$$\text{var}(\hat{\mu}) = (D'\Sigma^{-1}D)^{-1} \tag{8}$$

If Σ equals $\sigma^2 I$, it means that the sample plots are assumed to be independent and the estimator of standard error is the same as for simple random sampling (SRS) in classical sampling theory. A classical cluster design can be described by assuming a constant correlation within the clusters and by assuming the clusters to be mutually independent.

The other type is a model with additional variables X involved. With additional variables more complex sampling designs can be described, and the efficiency of estimation can be improved. These additional variables are assumed to be known in each point of the area concerned. Additional variables can be, for example, coordinates and altitude of sample plots as in this study. Coordinates can be useful if there is a trend in the area. In this case the estimators of standard error are comparable with classical estimators of systematic sampling, calculated with the aid of smoothed values. Also indicator variables (0-1) can be used. An indicator variable tells whether a certain point in the area belongs to a certain class or not. (e.g. Mandallaz, 1991). In this case the estimators are comparable with estimators of stratified sampling.

In this case the model can generally be presented as (e.g. Mandallaz, 1991)

$$y_1 = X_1\beta + e_i \tag{9}$$

the predictor of the population mean is

$$\hat{y} = \overline{X}\beta = \overline{X}'(X'\Sigma^{-1}X)^{-1}X'\Sigma^{-1}Y \tag{10}$$

and standard error of mean volume can be estimated by, for example,

$$\mathrm{var}(\hat{y}) = \overline{X}'\,\mathrm{var}(\beta)\overline{X} = \overline{X}'(X'\Sigma^{-1}X)^{-1}\overline{X} \tag{11}$$

The most difficult task in the general case is estimating the variance-covariance matrix Σ. This can be done by estimating a model of covariances as a function of distance between sample plots (e.g. Ripley, 1981). A somewhat simpler assumption would be a mixed model

$$y_{ji} = X_{ji}\beta + C_j + e_{ji} \tag{12}$$

where $c_j \sim N(0,\sigma_c^2)$ is the random cluster effect and $e_{ji} \sim N(0,\sigma_e^2)$ is the random plot effect, and c and e are independent. This model means that a constant correlation is assumed within a cluster, and clusters are assumed to be mutually independent.

If the model assumptions are not correct, $\mathrm{VAR}(\hat{y})$ can be a poor estimator of the quality of estimate $\hat{y}$. Thus, it is often wise to estimate the standard error of the mean volume using several different methods: if the results all fall within an acceptable range, the results are probably reliable (Mandallaz, 1991). It would also be advisable to take the sample using an objective method, although the model based method allows for the use of subjectively selected samples. If the model is not correct, a sample selected by a subjective method can give seriously biased results.

ESTIMATING THE TREND AND COVARIANCE FUNCTIONS

The parameters for the trend for the general model (9) and mixed model (12) were first estimated by the OLS method. The fitted trend of mean volume was a quadratic surface

$$y_i = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_1^2 + \beta_5 x_2^2 + \beta_6 x_3^2 + \beta_7 x_1 x_2 + \beta_8 x_1 x_3 + \beta_9 x_2 x_3 + \varepsilon \quad (14)$$

where

x_1, x_2 are the coordinates and

x_3 is the altitude

The variance-covariance matrices for the general model (9) was determined by estimating the covariance as a function of distance between plots. The residuals after least squares estimation were examined to suggest the suitable form of covariance function. In this study the Whittle's covariance function (Whittle, 1954; Ripley, 1981) was used, because of its flexibility in short distances.

For the estimation of correlation functions the data was separated into three sub-areas, because the time required for the calculations increases proportionally to the third power of the number of sample plots. The continuous covariance functions were estimated by the ML method (Cook & Pocock, 1983). The estimation was carried out using the grid search method (see also Kangas 1992).

After estimating the covariance functions (Fig 2.), trend parameters were estimated for the whole area by the GLS-method, assuming the covariance function as known. It was assumed that correlation between the clusters is negligible: the estimated correlations were below 0.001 when the distance was greater than 8 km. This assumption was made in order to simplify calculations. The effects of assumptions made are considered in Kangas (1992). The correlation functions used in the calculations were obtained by averaging the parameters of functions estimated for sub-areas.

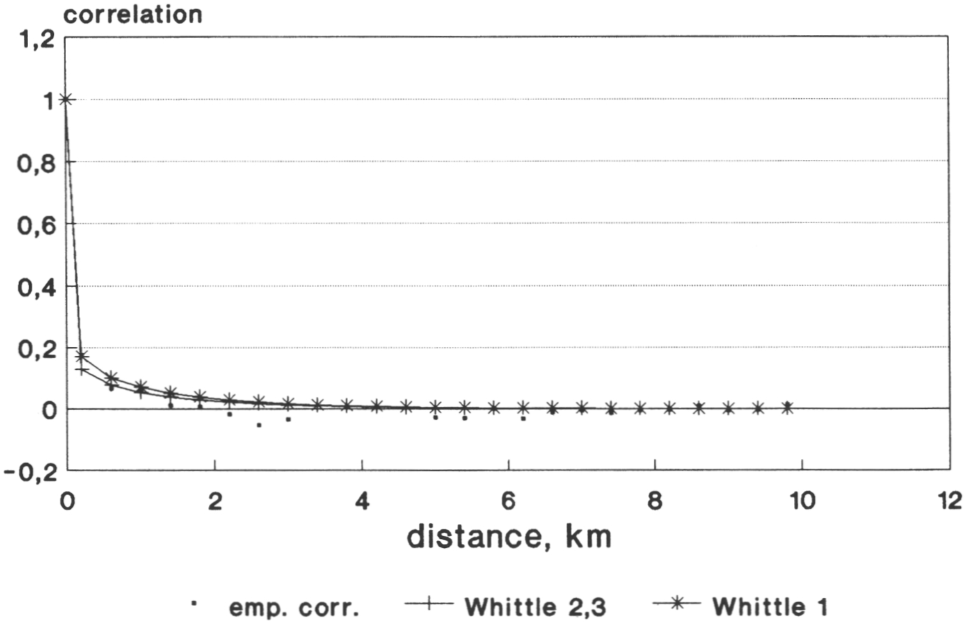


Fig. 2. The estimated correlation function and empirical correlations for plot volume as a function of distance between plots

The variances of random effects were estimated with the fitting-constants method of Henderson (Searle, 1971). The constant correlation within clusters was calculated from these variances. The correlation in the model with trend (12) was estimated to be 0.059. Also the percentage of forest land and it's standard error could be estimated with similar approach. Models for estimating the percentage of forest land are presented in Kangas (1992).

RESULTS

The estimated mean volumes and standard errors using different estimators are shown in Table 1. In the calculations, the estimates of mean volume obtained assuming independent errors (6) are considerably different when compared to other model based estimates, but they are the same as the classical estimates. calculated.

Table 1. The mean volume and standard error with different estimators. The estimators refer to different sampling designs. Model based estimators are for models (6), with independent errors, (9), with continuous covariance function and trend, (12), with constant within-cluster covariances and trend. The classical estimators of standard error are formula (3) for systematic sampling and formula for simple random sampling (SRS).

		mean volume		standard error	
		model	class	model	class
SRS	(6)	125.4	125.4	1.84	1.84
syst.	(9)	128.3	125.4	2.46	2.58
	(12)	128.6		2.40	

It seems that with both the model with trend and continuous covariance function (9) and the mixed model with trend (12), reliable estimates of standard errors for the systematic cluster sampling can be obtained. In the mixed model, the constant correlation is an underestimate in shortest distances, and the estimated standard errors are smaller than the error obtained using the quadratic form. The mixed model may still be an adequate approximation for most purposes.

In the empirical calculations of Päivinen (1987), the standard errors estimated with quadratic forms were overestimates when compared to the empirical results. In this respect, the errors estimated using models (9) and (12) might be quite near to the true standard error. It has to be remembered, however, that if the cluster design is changed, the distance between clusters, for example, or the number of sample plots per cluster, the between-cluster covariance should not be assumed to be negligible.

DISCUSSION

In this paper, model based estimators of mean values and standard errors for systematic cluster sampling were presented. Standard error estimates for models (9) and (12) were slightly smaller than those obtained with quadratic forms. The difference is, however, small, and to the correct direction - estimates obtained with quadratic forms have, in empirical studies overestimated the true standard errors. The model with trend and continuous covariance functions seems to be most reliable, but true standard errors are, however, not known, and thus it cannot be determined which of these estimators is best.

The difference between the classical estimators for SRS and model based estimators obtained, assuming correlation between sample plots was also considerable. Thus, not only the estimators of standard error, but also the estimators of mean, should be considered when an appropriate method is chosen. Correlations between sample plots have to be taken into account either by using model based estimators or by using estimators for cluster sampling.

Estimators based on quadratic forms are better in the sense that these forms do not require as much computer resources as model based estimators. Matrix calculations can be very time-consuming if the data set is large, and thus, simplifying assumptions are needed. On the other hand, model based estimators are better, because model and measurement errors can be taken into account, and because covariances can also be considered when mean values are estimated.

When a model-based approach is used, it is also easy to combine different sources of information in inventories. If a model with no additional variables (6) is used, estimates obtained from previous samples or from other sources of information can be used in a mixed estimator (Kangas, 1991). If a model with additional variables is used, the updated sample plots from previous inventories can be used in addition to new sample plots, when trend parameters are estimated, to reduce the variance of the model. The other possibility is to assume that we have prior information on the distribution of ß-parameters from other sources of information, and use this knowledge in the estimation process (e.g. Meng, Tang & Burk, 1990). The model can also be used as prior information when estimates for small areas are needed. Yet, the large area model may give biased estimates for small areas, if the model is not kalibrated.

However, the method presented needs further study. It has to be studied, how the characters, for example the size, of the area affect to the performance of the different estimators. In small areas it may be difficult to obtain reliable estimate of the covariance function. In large areas the covariance structure may be different in different parts of the area. In some areas the trend model used in this study may not be adequate or the process may not be isotropic. This kind of problems could make the estimation process even more difficult, but it is also possible to obtain new information of the areas considered.

REFERENCES

Cook, D.G. & Pocock, S.J. 1983. Multiple Regression in Geographical Mortality Studies, with Allowance for Spatially Correlated Errors. *Biometrics* 39, 361–371.

Kangas, A. 1991. Updated measurement data as prior information in forest inventory. *Silva Fennica* 25(3), 181–191.

Kangas, A. 1992. *Estimating the Parameters of systematic Cluster Sampling by Model Based Inference*. A submitted manuscript.

Korhonen, K.T. & Maltamo, M. 1991. The evaluation of forest inventory designs using correlation functions. *Silva Fennica* 25(2), 77–83.

Mandallaz, D. 1991. *A Unified Approach to Sampling Theory for Forest Inventory Based on Infinite Population and Superpopulation Models*. Doctoral thesis no. 9378. Swiss Federal Institute of Technology. Zurich. 256 p.

Matérn, B. 1947. *Metoder att upskatta noggrannheten vid linje- och provytetaxering*. Summary: Methods of estimating the accuracy of line and sample plots surveys. Meddelanden från Statens Skogsforskningsinstitut. Band 36(1). 138 p.

— 1960. *Spatial variation. Stochastic models and their application to some problems in forest surveys and other sampling investigations*. Meddelanden från Statens Skogsforskningsinstitut. Band 49(5). 144 p.

Meng, C.H., Tang, S.Z. & Burk, T.E. 1990. A Stochastic Restrictions Regression Model Approach to Volume Equation Estimation. *Forest Science* 36(1), 54–65.

Päivinen, R. 1987. *Metsän inventoinnin suunnittelumalli*. Summary: A planning model for forest inventory. Joensuu University, Publications in Sciences No. 11. 179 p.

Ranneby, B. 1981a. *Medelfelsformler till skattningar baserade på material från den 5:e riksskogstaxeringen*. (Estimation of standard errors in systematic sampling.) Swedish University of Agricultural sciences, Section of Forest Biometry. Report 21. Umeå. 19 p.

Ranneby, B. 1981b. *Den topografiska variationen inom olika områden*. En redovisning av skattade korrelationsfunktioner. Rapport 5. Sveriges lantbruksuniversitet, Institutionen för skogstaxering, Umeå. 54 p.

Ripley, B.D. 1981. *Spatial Statistics*. John Wiley & Sons. New York. 252 p.

Salminen, S. 1973. Tulosten luotettavuus ja karttatulostus valtakunnan metsien V inventoinnissa. Summary: Reliability of the results from the fifth national forest inventory and a presentation of an output-mapping technique. *Communicationes Instituti Forestalis Fenniae* 78(6). 64 p.

Searle, S.R. 1971. *Linear Models*. John Wiley & Sons. New York. 532 p.

Whittle, P. 1954. On the stationary processes on the plane. *Biometrica* 41, 434–449.

SAMPLING DESIGNS WITH SPECIAL EMPHASIS ON REMOTE SENSING

POSSIBILITIES OF ESTIMATING OVERGROUND STAND PHYTOMASS USING AERIAL IMAGES

Igor Danilin
Researcher
Laboratory of Forest Morphology
Institute of Forest,
Russian Academy of Sciences, Siberian Branch
Akademgorodok, Krasnoyarsk, Russia

ABSTRACT

One possibility to determine Larix sibirica Ledeb. stand overground phytomass parameters is by comparing the correlation with average tree height and crown diameter values obtained from black-and-white 1:5000 isopanchromatic aerial images. Regression equations for the relationships between various features have been developed and tested. Absolute errors of the imagery-based estimates are 36.4 m^3/ha for trunk woodstock and 14.4 ton/ha for overground standphytomass (absolutely dry). Relative errors are 17.7 and 12.9 per cent, respectively.

Keywords: Phytomass, regression equations, aerial images

INTRODUCTION

Assessment of the conditions and dynamics of forest communities by remote sensing methods and estimation of their productivity parameters are two problems of the highest priority in forest ecology monitoring. Many researchers in Russia and abroad have attempted to solve these problems (Sukhih et al. 1979; Cunia 1983; Kasile 1983; Vinogradov 1984; Borisov et al. 1987; Nelson et al. 1988; Paris and Kwong 1988; Danulis et al. 1989; Peretiagin and Borisov 1989;). In recent decades much effort has been made in the field of forest biomass remote sensing by space and airborne scanning, radar, and lidar systems (Cunia 1983; Nelson et al. 1988; Paris and Kwong 1988; Danulis et al.988; Timchenko 1990). Although these approaches to qualitative and quantitative assessments of biomass parameters in complex forest vegetation communities over large areas are very promising and have good prospects, the authors note that the data acquired by these approaches lack accuracy. Specifically, in estimating woodstock and biomass the error is over 50% (Nelson et al. 1988; Paris and Kwong 1988) it is quite clear that for the investigation of forest ceonotic population structure and productivity at the level of elementary geobotanical contours this accuracy is unacceptable (Vinogradov 1984). Thus, when solving these problems with the help of subsatellite survey it seems most reasonable to use highly informative aerial images of large and moderate scales (Kasile 1983; Borisov et al. 1987; Danulis et al. 1989; Peretiagin and Borisov 1989). Given the introduction of automatization into processing routine procedures, further refinements of methods and devices for forest imagery decoding, and a higher accuracy of output information the use of aerial imagery data seems very valuable (Sukhih et al. 1979; Borisov et al. 1987; Danulis et al. 1989; Peretiagin and Borisov 1989).

The objective of this work was to estimate the possibilities of using aerial images in recording the overground phytomass parameters in larch stands.

STUDY AREA, MATERIALS AND EXPERIMENTAL METHODS

The study was conducted in Larix sibirica Ledeb. phytocoenoses located in the subtaiga forest belt in eastern Hentey, Mongolia (Forests 1988). These are pure, pseudo-even-aged larch stands of different natural formation series growing in herb (mesophytic) forest type and aging from 16 to 70 years. Series of sample sites were settled in the upper reaches of the Kerulen river, on which all trees were mapped and measured using morphometrical methods (Danulis et al. 1989). To estimate phytomass characteristics, model trees were chosen on each site according to the principle of stepped representation (i.e. depending on trunk thickness) that were then divided into fractions, subject to analytical smoothing, and reduced to absolutely dry weight per hectare (Utkin 1975), (Table 1).

Table 1. Brief description of the representative sample sites.

Site number	Site size, (m^2)	Stand age, (years)	Average		Woodstock, m^3/ha	Density, trees/ha	Overground phytomass, ton/ha
			DBH, (cm)	Height, (m)			
1	200	16	1.6	3.8	39	60300	34
2	500	28	5.9	7.9	74	5700	55
3	300	30	7.5	9.5	212	19800	126
4	2400	37	18.4	15.4	305	1400	164
5	1000	70	18.9	18.1	397	2200	196

In our study we used black-and-white scale 1:5000 images (isopanchromatic film of T-42 type) acquired in 1990. The trees could be clearly distinguished in the images examined under the Sokkisha MS-27 stereoscope (Japan). In each sample site height and diameter of model trees were measured with the help of the Sokkisha parallaxometer. The values of taxation parameters derived from image analysis showed no unacceptable deviations when compared to ground measurements (Danulis et al. 1989).

RESULTS AND DISCUSSION

Correlation and factor analyses were carried out in order to examine the relationships between morphometrical parameters among trees and their phytomass values. The relationships between these features can adequately and effectively be described through parametric regression equations of

linear $y = a + bx,$ (1)

parabolic $y = a + bx + cx^2,$ (2)

and exponential $y = a \exp (bx + cx^2)$ (3)

types.

Among the most significant factors the following can be mentioned: DBH – diameter at the height 1.3 m above ground, cm; H – tree height, m; D – crown diameter, m. Approximations were chosen on the basis of maximum determination index values; determination index (r^2) ranges from 0.81 to 1.00.

Regression coefficients of morphometrical parameters for larch stands

Site number	Equation	Equation type	Regression coefficients			Determination index r^2
			a	b	c	
1	DBH f H	3	2.609	0.101	0.002	0.95
2		2	0.610	-0.152	0.142	0.99
3		3	2.864	0.072	0.002	0.97
4		2	-0.415	0.278	0.165	0.97
5		2	5.150	-1.644	0.213	1.00
1	DBH f D_c	1	-3.272	6.662	-	0.96
2		2	-5.897	7.562	-0.538	0.99
3		2	-2.748	9.862	-0.599	0.86
4		3	0.128	2.805	-0.469	0.96
5		1	0.072	5.714	-	0.97
1	D_c f H	3	1.419	-0.019	0.005	0.81
2		3	0.681	0.132	0.003	0.94
3		2	0.265	9.105	-1.045	0.98
4		2	0.280	2.389	-0.105	0.99
5		2	0.344	-0.147	0.029	0.97

From model trees on all the sample sites generalized equations were developed for estimating the volume of trunks with bark (V, m^3), and absolutely dry overground tree phytomass (P,kg).

Regression coefficients of morphometrical and productive parameters for larch stands

Equation	Equation type	Regression coefficients			Determination index r^2
		a	b	c	
V f DBH	2	-0.003	-0.002	0.001	0.99
V f H	3	0.0001	0.920	-0.024	0.79
P f DBH	2	-1.020	-0.952	0.388	0.98
P f H	3	0.060	0.819	-0.021	0.73
P f D_c	3	0.128	2.720	-0.238	0.65
P f $D_c H^2$	2	-8.842	0.929	-0.001	0.90
P f V	2	0.826	541.807	0.350	0.98

Analysis of the relationships shown above reveals that trunk volume and mass are most closely correlated with DBH. But at the condition of a closed canopy estimation of DBH by images only is, however, impossible because trunks are shadowed by crowns; that's why its value can be estimated through its relationships with D_c and H. In practice, values of volume and weight parameters can be more easily found using parabolic ratio, DBH H^2, which provides satisfactory accuracy ($r \geq 0.90$).

Using average crown diameter (D_c) and tree height (H), generalized equations were also developed for woodstock in the stand, presented in volume (M, m^3/ha) and weight (P, ton/ha) units. From the imagery-based measurements of 20 arbitrary selected trees estimates of D and H were determined.

Regression coefficients of morphometrical and productive parameters for larch stands

Equation	Equation type	Regression coefficients			Determination index r^2
		a	b	c	
M f D_c	1	12.459	18.417	-	0.90
M f H	1	-73.211	25.440	-	0.94
M f DBH	2	-9.337	24.990	-0.298	0.90
P f D_c	1	2.915	58.551	-	0.68
P f H	2	-20.034	13.193	-0.085	0.94
P f DBH	2	8.796	13.307	-0.229	0.92
P f M	1	21.158	0.442	-	0.99

The above data show that the closest correlation was obtained for the relationship between woodstock and phytomass and the average stand height ($r \geq 0.94$). These results agree with those acquired in an investigation of Quercus velutina Lam. stands in Ohio, USA (Kasile 1983).

Verification of the regression equations on the sites not included in this paper showed that, using the described method, imagery-based values have an absolute error of an order of 36,4 m^3/ha for trunk woodstock and 14,4 ton/ha for overground stand phytomass (absolutely dry). Relative errors are 17,7 and 12,9%, respectively, which for the forest inventory is an acceptable accuracy level for estimating volume and weight parameters from aerial images (Danulis et al. 1989).

If total larch stand phytomass is known, then, applying the data on its structure presented in Table 2, it is easy to determine mass values for various stand components, namely, crown mass, assimilation apparatus mass, and trunk mass.

Table 2. Larch stand overground phytomass structure (per cent)

Stand age, years	Density, trees/ha	Trunks		Branches		Needle
		wood	bark	live	dead	
16	60.3	35	16	35	1	13
28	5.7	43	15	26	6	10
30	19.8	60	17	9	11	3
37	1.4	68	14	10	6	2
70	2.2	74	15	6	4	1

The data resulted from our study can be applicable in regional forest monitoring for estimation of phytocoenoses state and dynamics in ecosystems disturbed by man.

REFERENCES

Borisov, A.N., Ivanov, V.A., Ivanchenko, G.A. et al., 1987: Selection of algorithms of aerial information automated processing in the context of forest management problems. In Investigation of forests by space and aerial monitoring methods. "Nauka" Publishing House, Siberian Department, Novosibirsk, pp. 62–72 (in Russian).

Cunia, T., 1983: Forest inventories as the basis for a continuous monitoring of forest biomass resources. In Biomass Util. Proc. NATO Adv. Study, Inst. Alcabideche, Sept. 26 – Oct. 9, 1982. New-York; London, pp. 63–101.

Danulis, E.P., Zirin V.M., Sukhih V.M., Elman, R.I., 1989: Remote sensing in forest management. "Agropromizdat" Publishing House, Moscow, 233 p. (in Russian).

Forests Of Mongolian People's Republic. Larch stands in the Eastern Hentey, 1988:"Nauka" Publishing House, Moscow, 176 p. (in Russian).

Kasile J., 1983: Aerial photo biomass equation. In Biomass Util. Proc. NATO Adv. Study, Inst. Alcabideche, Sept. 26 – Oct. 9, 1982. New-York; London, pp. 103–107.

Nelson, R., Krabill, W., Tonelli, J., 1988: Estimating forest biomass and volume using airborne laser data. Remote Sensing of Environment, vol. 24, no. 2, pp. 247–267.

Nelson, R., Swift, R., Krabill, W., 1988: Using airborne lasers to estimate forest canopy and stand characteristics. Journal of Forestry, vol. 86, no. 10, pp. 31–38.

Paris, J. and Kwong, H., 1988: Characterization of vegetation with combined thematic mapper and Shutle imagine radar image data. Photogrammetric Engineering and Remote Sensing, vol. 54, no. 8, pp. 1187–1193.

Peretiagin, G.I. and Borisov, A.N., 1989: Estimating pine stand woodstock using aerial images. In Forest productivity factors. "Nauka" Publishing House, Novosibirsk, pp. 147–154 (in Russian).

Sukhih, V.I., Sinitsin, S.G., Apostolov, U.S. et al., 1979: Space and aerial monitoring methods in forest management and protection. "Lesnaja Promyshlennost'" Publishing House, Moscow, 288 p. (in Russian).

Timchenko, M.I., 1990: Estimating pine stand biological productivity using remote sensing data. In Space and aerial monitoring of taiga forests. Proceeding of All-Union Conference. Institute of Forest and Wood, USSR Academy of Sciences, Siberian Branch, Krasnoyarsk, pp. 97–98 (in Russian).

Uutkin, A.I., 1975: Biological productivity of forests (methods of investigation and results). In Forestry and Silviculture. VINITI, vol. 1, Moscow, pp. 9–189 (in Russian).

Vinogradov, B.V., 1984: Space and aerial monitoring of ecosystems. "Nauka" Publishing House, Moscow, 320 p. (in Russian).

MONITORING OF MANGROVE FOREST CHANGES USING HIGH RESOLUTION SATELLITE IMAGERY

Khali Aziz Hamzah *, Azman Hassan* and Chong Phang Fee**
*Research Officers, Natural Forest Division
**Senior Research Assistant, Natural Forest Division
Forest Research Institute Malaysia (FRIM) Kepong,
Kuala Lumpur, Malaysia

ABSTRACT

Mangroves are salttolerant forest ecosystems of tropical and subtropical intertidal regions of the world. Mangroves plays an important role in Malaysia's economy and constitutes a reservoir and refuge for many plants and animals. Recognizing the importance of mangrove forests, the need is there to accurately map and monitor these forest areas. This is particularly important in the country's effort to ensure correct and appropriate strategy and planning to sustain the resource for the future , both ecologically and economically. This paper will focus on the use of remotely sensed data for monitoring changes in the Klang Mangrove Forest in Peninsular Malaysia.

Keywords: Mangrove forest, remote sensing, forest monitoring

INTRODUCTION

Malaysia is located within latitudes 1° to 7°N and longitudes 100° to 119°E. The total land area is estimated to be 32.86 million hectares which comprises of Peninsular Malaysia (West Malaysia), Sabah and Sarawak (East Malaysia). West Malaysia is separated from East Malaysia by 720 km of the South China Sea giving the country a coastline of almost 4830 km in length. Being a tropical country, the climate of Malaysia is typically humid tropical or wet equatorial and is characterized by year round high temperatures and seasonal heavy rain. The average rainfall is about 2,540 mm per annum. The mean temperatures during the day and night are 32° and 22°C respectively.

FORESTRY IN MALAYSIA

Forest in Malaysia can be broadly classified broadly into 3 major types namely Dipterocarp Forest, Swamp Forest and Mangrove Forest. These forests cover about 57.3 % of the total land area in Malaysia. In Peninsular Malaysia alone the extent of Dipterocarp Forest, Swamp Forest and Mangrove Forest are about 5.6 million, 0.20 million and 0.10 million hectares respectively. Table 1 shows the extent of the different forest types for Peninsular Malaysia, Sabah and Sarawak.

Table 1. Distribution and extent of major forest types in Malaysia (million ha)

Region	Land area	Mixed Dipt forest	Swamp forest	Mangrove forest	Total forested land	Percentage total of forested land
Peninsular Malaysia*	13.16	5.67	0.20	0.10	5.97	45.30
Sabah**	7.37	3.93	0.19	0.32	4.44	60.30
Sarawak+	12.33	7.30	1.24	0.16	8.54	69.26
Malaysia (Total)	32.86	16.90	1.63	0.58	18.95	57.66

Sources:
* Forestry Department, 1992
** Domingo and Yahya, 1989
\+ Mengga and Roland, 1992.

This diverse forest ecosystem and the diversity in terms of forest resources lead to many management problems. One obvious problem is with regards to the forest monitoring aspects. The conventional method of monitoring forest resources in Malaysia is through national forest inventory which is undertaken once every ten years. This is normally carried out with the use of aerial photographs for typing and ground survey as checks .This involve quite significant budget in terms of manpower and time. An alternative approach which can minimize these constrains is by using remote sensing data to monitor the forest resources. A number of studies on the use of remote sensing for forestry application in Peninsular Malaysia has been described by Khali (1992). All the studies were done in inland and peat swampforests. Consequently a study on the use of remote sensing technique to monitor mangrove forest changes was conducted.

MANGROVE FOREST IN PENINSULAR MALAYSIA

Mangroves are salt-tolerant forest ecosystems of tropical and subtropical intertidal regions of the world. Mangroves forest in Peninsular Malaysia can be found mainly in three major areas namely Perak, Selangor and Johor (Chan, 1987). Figure 1 shows the distribution of major mangrove forests in Peninsular Malaysia. The forests are managed on sustained yield basis under 30, 25, and 20 years rotation periods for Perak, Selangor and Johor respectively.

Mangrove forests play an important part in the economy and constitutes a reservoir and refuge for many plants and animals. In recognition of the importance of mangrove ecosystems as a renewable source of wood materials, breeding and nesting habitats for aquatic life and terrestrial fauna, feeding ground for migratory birds and for the control of coastal erosion, the 10th Malaysian Forestry Conference, 1989 (Forestry Department, 1992) has adopted four resolutions concerning it namely:

a. that state Forestry Departments of Johor, Perak, Selangor and Negeri Sembilan should continue to reforest unproductive mangrove forest by planting of mangrove seedlings such as Bakau Minyak (Rhizophora apiculata) and Bakau Kurap (Rhizo phora mucronata) .

b. to practice appropriate reforestation techniques based on ecological rational for rehabilitating and developing mangrove forest. One such successful technique is the acceleration of successional Avicennia Forest to productive Rhizo phora Forest. It was made possible through the introduction of a new silvicultural technique of using potted Rhizophora seedlings to plant up the deeply flooded area.

c. that Land Development Agencies carry out Environmental Impact Assessment (EIA's) studies for project involving the conversion of mangrove areas to other uses and such findings be presented to higher authorities prior to implementation. This is to safeguard the important aspect of conservation and environmental protection functions of the mangrove ecosystems.

d. that Forestry Department of Peninsular Malaysia to continue the practice of multiple use approach for the preparation of future mangrove forest management plans. This is in line with the objective of sustainable forest resource management and to maximize benefits derived from the mangrove forest.

Recognizing the importance of the mangrove forests in this country, there is a need to accurately map and monitor the forest areas to ensure that a correct and appropriate strategy and planning of the resource for the future, both ecologically and economically can be achieved. As such a study was conducted using remote sensing technique with the main objective to find out changes that occurred in the mangrove forest from 1974 to 1991.

STUDY AREA

The study area is located in the Klang area in the state of Selangor, which is about 25 km from Kuala Lumpur (Figure 2). The area include mangrove forests on the islands of Pulau Ketam, Pulau Tengah, Pulau Kelang, Pulau Lumut, Pulau Pintu Gading, Pulau Che Mat Zin and Pulau Selat Kering as well as mangrove forest along the coastal area of the mainland. It covers a total land area of about 44000 hectares

APPROACH

Basically the study involved three main components namely data acquisition, data analysis and field works. A 1974 land-use map with the scale of 1:126,720 was used as a base map. It is expected that a lot of changes had occurred since then. Another Land Use Map prepared in 1984 was also used. These two maps were overlaid and land use changes between the two dates were noted. Emphasis was given on the changes of the mangrove forest area. A Landsat TM Image dated 22/2/1991 was acquired from Malaysian Center For Remote Sensing (MACRES) in Kuala Lumpur. The full scene cloud free data was downloaded into MERIDIAN image processing system and a subset of the study area covering 2824 km2 was made. These data were georeferenced to the map projection system use in Malaysia known as Rectified Skew Orthomorpic Projection system (RSO) for further analysis. Classification of the image was done using MERIDIAN image processing system.

The 1984 Land-use map was digitized using SPAN geographic information system and further reclassified into four classes know as Mangrove Forest (Class I), Forest lost from 1974 to 1984 (Class II), Non-forest (Class III), and Mudflats (Class IV). The digitized data were further transferred into MERIDIAN system and was overlaid against the TM image of the study area. All changes of the areas were then marked and digitized using screen digitizing menu of the system. Area analysis was conducted to find out the extent of changes occurred from 1974 to 1991.

RESULTS AND DISCUSSION

The mangrove vegetation in the study area is simple in structure varying from 6 to 24 m in height. The canopy is comparatively even and unbroken while few species grow in the understorey layer. The principle tree species are characterized by special root formations such as stilt roots (Rhizophora spp.) and pneumatophores (Avicennia, Bruguiera and Sonneratia spp.). Mangrove forest in this area is use for the production of charcoal, firewood and poles. They are also the source of "nipah" (Nypa fruticans) leaves for thatching and cigarette rolls and sap for sugar and bark for tannin.

On the whole, it was found that there has been a slow but sure reduction of mangrove areas in the study area. Mangrove forest in 1984 accounted for about 26945 hectares or 61.19% of the study area. Comparing to the area in 1974, about 3368 hectares of the mangrove forests have been converted to other land uses (Table2). Figure 3 shows the extent of the mangrove forest based on the 1984 land use map.

One important aspect of image processing is to select bands combination for making enhanced color composite image which is suitable for interpreting vegetations types. In this study different TM bands combination tested gave different results. It was found that combination of bands 4, 5, and 3 (RGB) in the FCC gave good results in differentiating vegetation and bare land. Combination of these bands in the FCC also showed mangrove forests very well. Consequently, this TM bands combination (453 RGB) was finally adopted for the image processing in this study. Result from the image classification showed that in 1991 the mangrove forest in the study area accounted for about 23085 hectares as compared to 26945 hectares in 1984 and 30312 hectares in 1974 (Table 3). This mean that during the seventeen years period, about 7227 hectares or 23.84% of the mangrove forests in Klang area have been converted to other land use. Based on this information the average conversion rate of the mangrove forest is about 430 hectares per year. However the actual conversion rate is not constant through out the year. For the first ten year period (1974 to 1984) the mangrove lost was about 3367 hectares or 11.1% (conversion rate of about 340 hectares per year), where as for the last seven years (1984 to 1991) the loss has slightly increased to 3860 hectares or 14.32% (conversion rate of about 550 hectares) due to rapid land development activities in the area in the late 1980's. The conversion rate is rather high because it includes forests area which has been gazetted for other uses. Field observation conducted confirmed that on the islands most of the areas has been converted into agriculture area. In contrast, along the main land coast the changes were mainly due to the development of the mangrove forest into residential area, ports and their related infrastructures, particularly in the unproductive or poor mangrove forest.

Table 2. The extent of mangrove forest in 1984.

Class		Area (hectare)
Class I	(Mangrove Forest)	26945
Class II	(Mangrove lost 1974 –1984)	3367
Class III	(Non-Mangrove)	12546
Class IV	(Mud-flats)	1173
Total		44031

Under natural conditions, the mangrove ecosystem undergoes continuous changes. These changes could be as a result of either formation of new mangrove shores; accretion due to sedimentation from suspended silt from upstream or materials washed by rain from higher grounds, and loss of areas due to natural erosion. Areas which have been eroded due to natural causes such as strong natural currents and occasional coastal storms can also grow back naturally (Saenger et al., 1983). The long gaps between NFI will not be able to reflect these continuous changes. The use of remote sensing techniques, with its more frequent coverage and barring any cloud interference, will be a more effective, cost efficient and competent way of monitoring not only these changes

but also changes due to man's intrusion into the mangroves. From this study, combination of ancillary data with remote sensing technique proved to be very useful for monitoring mangroves forest changes.

Generally, the depletion of mangrove areas is more significant near densely populated areas such as the Klang area, where the mangrove land has to compete for more tangible land use. Note worthy however is the fact that mangrove forests with a long history of management tend to withstand better pressures against conversion. The Matang mangroves in Perak, Malaysia which has come under intensive management since the twentieth century has actually increased by about 3% in area in the last 30 years, thus clearly reflecting the advantages of proper forest management (Darus and Othman, 1983).

Table 3. The extent of Mangrove Forest in Klang area

Year	Mangrove Forest (hectares)
1974	30312
1984	26945
1991	23085

CONCLUSION

Mangrove forests are an important source of timber and at the same time also protect the coastline. As a renewable resource, they should be properly managed. Since monitoring is the first and one of the most crucial steps for proper management, appropriate efforts based on proven technologies should be undertaken to better manage the mangrove forest ecosystem. Using satellite technology to observe the earth from space has proven to be a cost-effective and efficient way to monitor the ecosystem. Greater and wider use of this new and emerging technology in tropical forest ecosystem monitoring and management is therefore essential.

However, remote sensing is only a tool to monitor and does not itself provide solution to any natural resources and natural environment degradation process. Remote sensing will be able to provide base line information for taking preventive measures to prohibit or reduce the on-going process of environmental degradation. By providing potential and existing status of mangrove forest resources, remote sensing may be able to contribute to greater understanding of its dynamics and enable planners and policy makers to undertake timely and appropriate measures for sustained development efforts.

ACKNOWLEDGEMENT

The authors wish to thank the Director General of FRIM and Director of Natural Forest Division FRIM , for their support and permission to present this paper. The authors would also like to thank the Director of Malaysian Center For Remote Sensing for allowing them to use their laboratory facilities.

REFERENCES

Chan, H.T. 1987. Country Report. In : Mangroves of ASIA and the Pacific: Status and Management. Technical Report of the UNDP/UNESCO Research and Training Pilot Program on Mangrove Ecosystem in Asia and The Pacific (RAS/79/002) United Nations Educational, Scientific and Cultural Organization. pp 538.

Darus, M.M. and Othman, M. 1983. Management and Utilization of Mangrove Forests in the Asia Pacific Region. In the Proceeding of the Workshop on Productivity of the Mangrove Ecosystem: Management implications. 4 –6 Oct. 1983, Penang Malaysia. pp 183.

Domingo Chai and Yahya Awang. 1989. Current Forest Resource Scenario in Sabah. Paper presented at the MTIB Marketing Seminar –Preparing for the 1990's, 27 –28 February 1989, Kuala Lumpur, Malaysia.

Forestry Department, Peninsular Malaysia. 1992. Forestry Sector in Peninsular Malaysia. Unpublished Report.

Forestry Department, 1992. Pre-Proceeding of the 11th Malaysian Forestry Conference, 27 July –2 Aug. 1992, Kota Kinabalu,Sabah, Malaysia.

Khali Aziz Hamzah, 1992. Forest Ecosystem in Peninsular Malaysia –Monitoring and Management Using Satellite Remote Sensing Technique. Paper presented at the ISY Regional Seminar on Tropical Ecosystem –Remote Sensing Applications to Tropical Ecosystem Management, June 14 –20 1992, Khao Yai National Park, Thailand.

Mangga, M. and R.J. Roland, 1992. Managing Natural Forests for Sustaining Timber Production Towards 2020. Paper presented in the 11th Malaysian Forestry Conference, 27 July to 2 August, 1992, Kota Kinabalu Sabah, Malaysia.

Saenger, P., E.J. Hegerl, and J.D.S. Davie, 1983. GlobalStatus of Mangrove Ecosystems. IUCN Commission of Ecology Paper No.3.

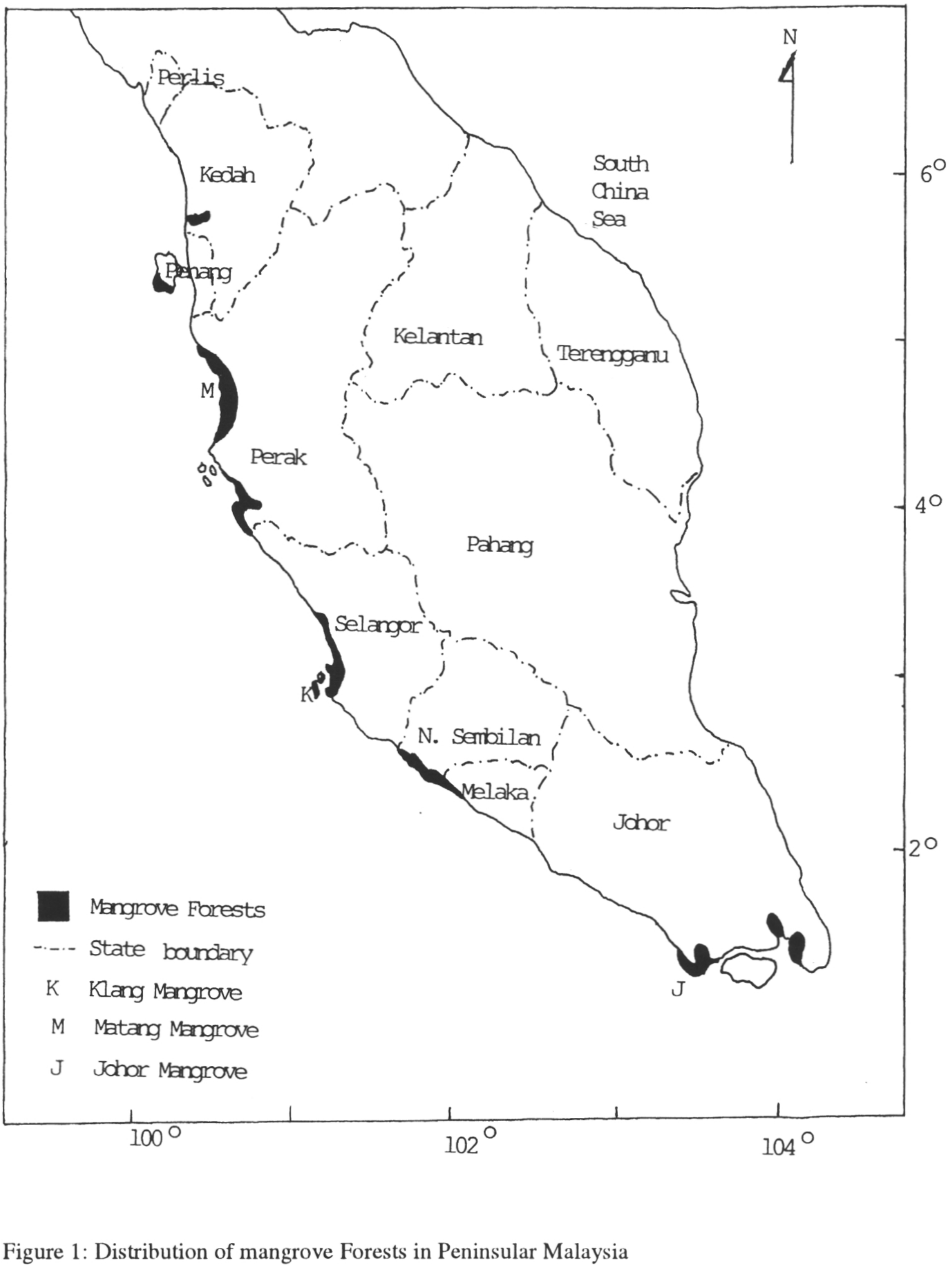


Figure 1: Distribution of mangrove Forests in Peninsular Malaysia

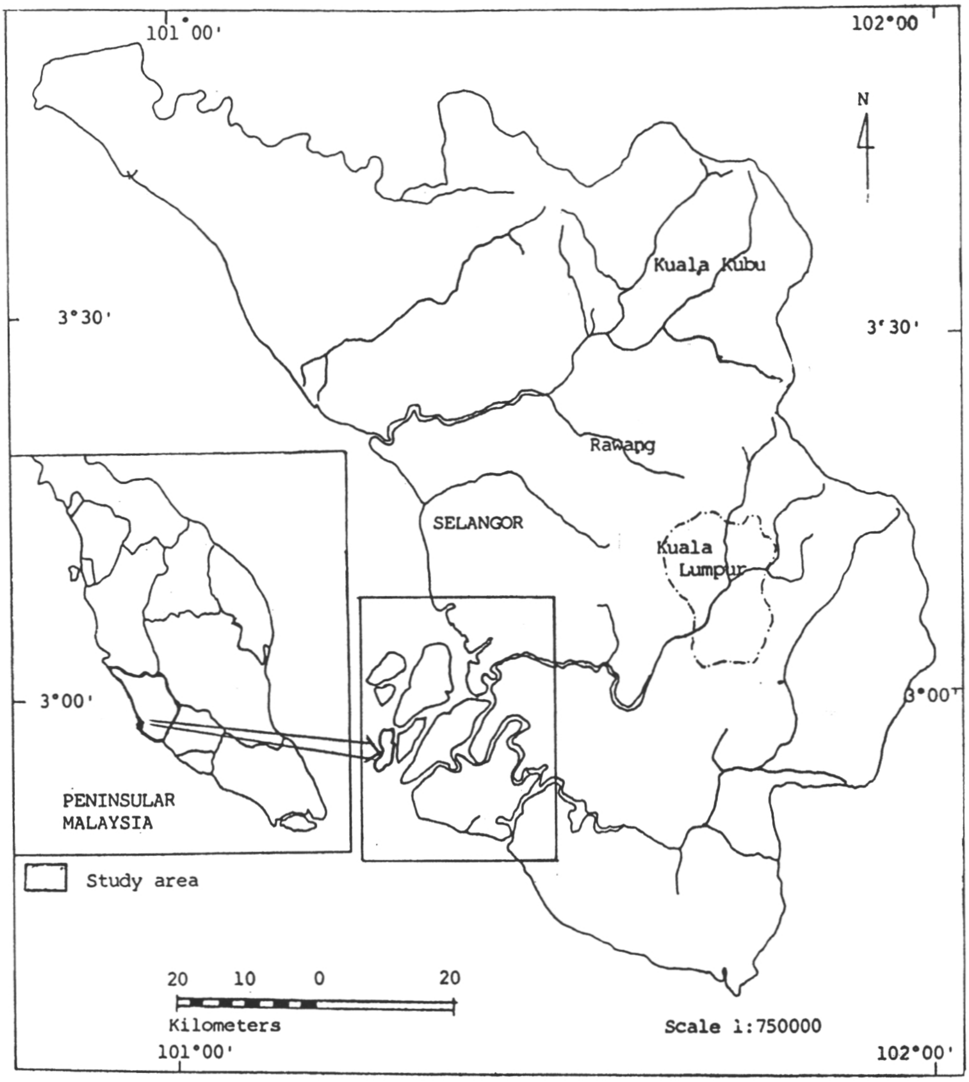


Figure 2: Location of the study area

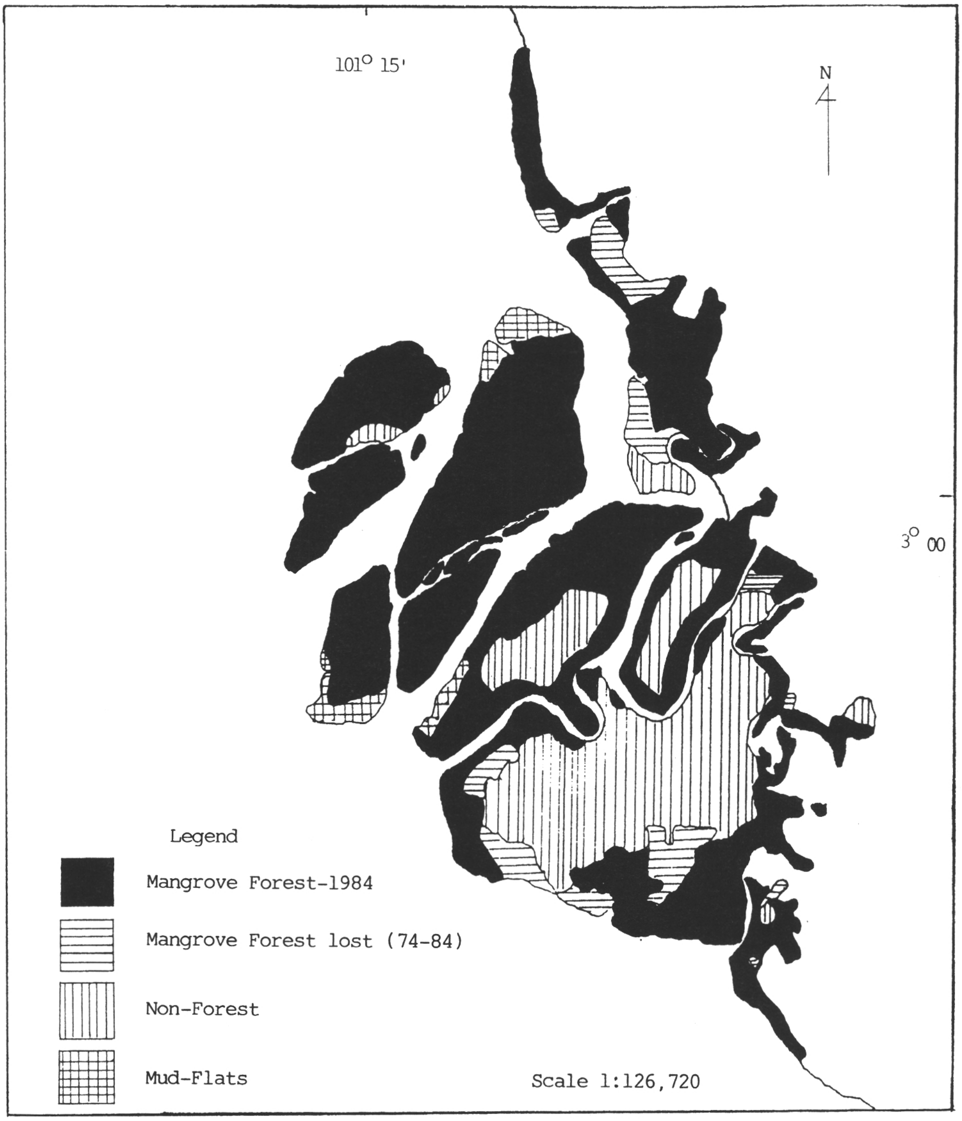


Figure 3: The extent of Mangrove Forestst in Klang, Selangor

A METHOD OF MONITORING FOREST RESOURCES USING MULTI-TEMPORAL AND MULTI-SOURCE REMOTE SENSING COMBINED WITH GROUND SURVEY

You Xianxiang, Xu Dingcheng and Han Xichun
Beijing Forestry University
Beijing, China

ABSTRACT

Remote sensing material experimented consisted of Landsat MSS, October 1976 and 1986, Landsat TM, June 1986 and August 1990, aerial photos, black and white 1958 and colour infrared 1980.

For Landsat MSS data, density values, vegetation index values, vegetation index based on normalised density values and multi-temporal classification, KL analysis, were compared. The results showed that the multi-temporal classification was best with an accuracy of 78.4%. Multi-temporal combination of TM was capable to display clear-cut areas with an accuracy of more than 90%.

The combination of black-and-white and colour infrared aerial photos and TM images were used to measure the change. All kinds of changes could be distinguished from the two period aerial photography. However, large areas require enormous investments, and long working periods and the geometric errors are substantial if not corrected. Satellite images, on the other hand, are relatively cheap, and, if the two images from different years are taken in the same season, change characters can be displayed exactly. Geometric correction for satellite images is easy.

Keywords: Forest monitoring, Remote sensing, Information integration

THE USE OF INTEGRATED GROUND AND REMOTELY SENSED DATA FOR FOREST MONITORING OF THE SUDETY MOUNTAINS

B. De Roover *, T. Zawila-Niedzwiecki **, G. Mierzwinski **,
R. Goossens *, A. Ciolkosz **
* Laboratory of Remote Sensing and Forest Management,
University of Gent, Faculty of Agricultural Sciences (Belgium)
** OPOLIS-Remote Sensing and Spatial Information Center,
Institute of Geodesy and Cartography in Warsaw (Poland)

ABSTRACT

The paper presents the preliminary results of a forest monitoring project being carried out in the Polish part of the Sudety Mountains, one of the most polluted regions in the world. Constant heavy air pollution during the past 40 years is one of the main causes of forest decline, which has dramatically increased since the end of the 1970's. For the purpose of the project, satellite images have been analysed and compared with information derived from aerial photographs, archived forest maps as well as ground truth data. A performant geographic information system, integrating the forest data, allows to analyse the different levels of information concerning the state of forest. Although the research has not yet been completed, the results acquired up to now indicate that remote sensing should be a tool of large area forest monitoring, especially in heavily damaged regions, and that GIS is a powerful tool for interpretation and management of spatial and relational forest datasets.

Keywords: forest damage, monitoring, remote sensing, GIS

INTRODUCTION

Since several years European forests have been progressively damaged by industrial air pollution. Increases of the pollution could be observed in concordance with the prevailing wind direction i.e. from SW to NE. That is why a particularly serious situation is developing in central Europe. In Poland, due to its geographical location, one can observe accumulation of air pollution, not only domestic but also emitted in South and West of Europe. This factor, linked with the low quality of the forest sites and variability of the weather from year to year, caused environmental deterioration. Under these circumstances the introduction of monocultures on large areas facilitates the occurence of insects and parasitical fungi.

Forests on the elevated sites are composed of fir (*Abies alba*), spruce (*Picea abies*) and beech (*Fagus silvatica*), the most sensitive species to the pollution. This is why the forest decline is strongly manifested in montaineous regions.

The rapid changes of environmental conditions and the large extend of damage imply the use of performant methods for forest assessment. Therefore remote sensing could be considered as a monitoring tool and satellite data could play an increasing role in this activity.

In order to verify the utility of the satellite data to forestry, the Large Area Operational Experiment for Forest Damage Monitoring in Europe Using Satellite Remote Sensing was organized. The objectives of the Experiment, carrying out under the auspices of the FAO European Forestry Commission and coordinated by UNEP-GRID in Geneva, are to assess the current state of the forest using satellite sensing and to evaluate the operational methodology of the regional forest monitoring, based on satellite data and linked to the traditional methods of forest assessment. Multitemporal satellite images could be treated as an objective tool describing the change in forest condition status over the time.

This paper presents the preliminary results of the pilot project, executed within the European Experiment mentioned above and covering the ecologically disastered area of the Sudety Mountains in Poland. Presented project is supported by the Polish National Forests and is curried out by OPOLIS-Remote Sensing and Spatial Information Center of the Institute of Geodesy and Cartography in Warsaw (Poland), in cooperation with the Laboratory of Remote Sensing and Forest Management-University Gent (Belgium) and the Institute for the Study of Earth, Oceans and Space-University of New Hamshire (USA).

MATERIALS AND METHODS

Three test sites (8000 ha, 10000 ha, 12000 ha), located in the western part of the Sudety Mountains and covered by spruce stands, were selected for the project execution. Two sets of information are used: ground and remotely sensed data.

Guiding principles for ground forest inventory within the reported project have been defined jointly with BULiGL-Forest Management and Geodesy Bureau and IBL-Forest Research Institute in Warsaw (Grzyb and Dmyterko, 1990), following the directives described by the Team of Experts of the UN-Economic Commission for Europe on Satellite Detection of Forest Damage.

It was assumed that each test site should include: stands at four main age classes, young stands, uneven-aged stands and understorey regenerations. Test site should comprise stands characterised by different sites (dry, well-drained and marshy). All observations within each of three test sites were performed on minimum 150 homogeneous test areas (1–10 ha), consisting of 1 to 3 circular sample plots.

The description of each test area includes the following elements:

1) terrain description (type, shape, slope, aspect, height a.s.l., type of soil and site, ground cover),
2) stand description (structure, species, age, mixture, density, H, d.b.h., H of first living branch, number of trees per area unit, number of dead and dying trees and occurance of cones),
3) assessment of forest condition – described by defoliation index (Df), discolouration of needles (index Dc) and damage index (Dm). Df and Dc indexes were assessed following the recommendations of the International Cooperative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP-Forest). Dm was calculated on the base of defoliation, height increament and vitality assessment (Dmyterko, 1990 and 1991).

The set of remotely sensed data comprises three types of information:

1) spectral field measurements,
2) aerial photographs,
3) satellite images.

Some field spectral measurements were performed in order to evaluate the leaf area index (LAI), as well as to determine the condition of trees, as needle reflectance highly correlates with chlorophyll levels, extend of cellular damage, amount of foliar water and degree of senescence (Rock, 1992).

As far as aerial data is concerned, only archived CIR photographs have been used. Unfortunatedly, bad weather condition unabled capture of the aerial photos during the 1991. They are planned to be acquired in 1992. However maps of the forest condition (1:25000) based on colour infrared (CIR) aerial photographs taken in 1984 are used during the project execution.

Within the project different types of satellite data are used. Landsat Thematic Mapper (TM) images from 11 July 1984, 29 August 1990 and 1 September 1991 have been analyzed. SPOT and Cosmos images were used, but in the limited scope, due to their spectral resolution. Microwave data (ERS-1 and ALMAZ) are also considered to be analysed (images are registered but not yet delivered).

Satellite data were interpreted, using both digital and hybrid (visual/digital) methods of image classification, to assess actual forest state status as well as to evaluate the rate of change over time. Satellite spectral characteristics were statistically compared with ground measurements in order to find out the relationships between these two levels of data capture.

Results of ground truth observations and measurements were analysed in relation to spectral responses of the test areas, derived from proper TM bands as well as from ratio channels (TM5/4 and TM4/3), normalised vegetation index (NDVI=(TM4–TM3)/(TM4+TM3)), brillance (Br=square root$\{(TM3)^2+(TM4)^2\}$) and principal components (PC1, 2, 3). Analysis of spectral characteristics versus stand and site parameters were performed for the entire dataset and separetely for each aspect (nine classes), slope (six classes) and aspect and jointly for particular aspect, slope and class of age. Both regression analysis and multivariate analysis were applied.

Due to the quantity of information its analysis couldn't be possible using only traditional methods, so the intensive works on establishing the geographic information system (GIS) database were undertaken. The first stage of our works comprises the establishment of a spatial database consisting of following levels of information:

1) digital terrain model (DTM) – based on the scanned contour maps on a scale of 1:25000,
2) forest condition 1984 – digitized from the maps elaborated on the base of CIR aerial photographs, taken in 1984,
3) TM classification 1990,
4) forest administrative units (parcels and districts boundaries),
5) hydrography,
6) transportation.

In the near future the following levels will be added: soils, geology, forest sites, concentration of industrial pollutions.

RESULTS

Only a limited number of significant linear regressions describing statistical relationships between elements which were analysed, have been found. The strongest connections were found between spectral responses versus damage, defoliation and discolouration indexes. The most interesting results are presented in table 1. As it was expected, quite good conjunctions exist between the spectral characteristics of stands and damage classes, when the forest is situated on S and SW aspects (sun illumination). No significant relations were found as far as other stand parameters are concerned. However all these results should be interpreted very carefuly because the linear correlation does not prove sufficiently the relationship in such complicated ecosystem. It seems to be evident that interaction effects play an important role within measured elements, therefore the multivariate analysis may give a more precise description of the studied phenomena.

During the first stage of the multivariate analisis the data were restricted to the stands with a closed canopy cover and characterised by damage (Dm), defoliation (Df) and discolouration (Dc) indexes, as well as age of trees. Opposit to the linear regression, multivariate analysis comprises stand parameters as dependent and spectral characteristics as independent variables. Examples of obtained expressions are presented in table 2.

As far as defoliation and damage models are concerned, a high correlation coefficient is noted: R^2adjusted (R^2a) exceeds 0.90 and on the S-aspects even reaches 0.97. Only in the case of expressions describing discolouration of needles in the stands located on E, SE and W slopes, the R^2a value doesn't exceed 0.55 and in the best correlated formulas (concerning N-aspect) reaches 0.87. The use of proper TM channels, for describing Df and Dm, results, for almost all slopes, in R^2a values exceeding 0.9, with exception for E-aspects.

No significant improvement of correlation by using the ratio bands were observed. Rather surprising is that the presented expressions didn't contain any ratio channels which, according to our previous studies (Zawila-Niedzwiecki, 1989), seemed to be useful to assess the spruce forest condition. This allows to the conclusion that in such heavy impaired forests even proper TM channels enable to delineate the damage zones.

During the calculation we tryed to include to the expressions the ground measured stand parameters as one of the variables. Presented models show that only the age of forest stands has an influence but in many cases it was also eliminated during the computation. This variable is important on N, E, SW and NW aspects only.

Analysis of multilayer spatial data indicates that forest decline phenomena are occuring within the whole study region. This agrees with the results from analysis based on aerial photos and satellite images (Polawski et al., 1987), wherein it was concluded that the forest condition is of low quality in the region.

Using supervised classification of Landsat TM data, acquired in 1984 and 1990, the rate of change in the forests was evaluated. The change during the six years period have been assessed on the base of data concerning areal extend of different damage classes (table 3).

Because of the soil erosion risk, the understorey regenerations and only small clear cuts were the common practice on the territory under study. Now, due to decline processes one can observe decrease in stand density and canopy closure as well as increase of clear cut areas. So that the extention of openings could be treated as a kind of forest change index. Analysis of stored data show a large distribution of clear cuts, which are observed starting from 600 m a.s.l. and above 750 m are extensive. Table 3 shows also that during last six years, within studying region one can observe: decrease of the area covered by damage and dying stands what is an effect of cutting activity; increase of surface covered by young and mixed stands as well as decrease of bare open areas, as a result of afforestation activities.

CONCLUSIONS

On the present stage of our research, following linear regression analysis, we can constate that on the illuminated slopes (S, SE, SW) the condition of the stands could be quite well interpreted using only proper TM channels, but on the shaded slopes (N) the use of ratio bands (especially NDVI, PC and Br) could be profitable.

Statistical analysis indicate however that linear regression doesn't explain enough the relationships between stand parameters and spectral responces, registered by TM scanner. Nevertheless multiple correlations could describe the variability of the studying elements in relation to spectral data. For instance expression (13), in the table 2, presents that on the south aspects 97% of the sum of the squares of the deviations of the Df values about their mean is attributed to the relationship between Df and TM1, 2, 5. In other words, 97% of the variability of defoliation index, on the south aspects, could be derived from spectral characteristics registered in TM1, 2 and 5. It should be clearly said that the parameters in presented models are not universal and relate only to investigated parcels. However the received results allow to the conclusions describing general relations between the data, derived from TM images, and the ground stand characteristics.

The defoliation and damage indexes seem to be the most useful for further works on satellite based assessment of forest condition. Especially the damage index, proposed by the Forest Research Institute in Warsaw (Dmyterko, 1991), is well correlated with spectral characteristics derived from TM data. On the contrary the needles discolouration are not considered as significant enough to describe the forest condition in relation to the satellite data.

The reported study demonstrates that satellite images could deliver the information concerning damage zones in spruce stands and clear cuts extention. Such information could be useful for regional monitoring, particularely during the large area forest inventories as well as ad hoc monitoring between consecutive forest inventories, which are performed in the Polish forest every ten years. When used in conjunction with other forest data, stored in GIS datasets, satellite images could play an increasing role in the forest economy.

The multidate satellite classifications indicate that the forest decline in the Sudety region is observed within the whole area under study and show that decline processes are developing even though the activity of the forest service seems more efficient than in the first half of 80's.

On the presented stage of our study high relationships of forest damage to TM-spectral characteristics were found. Received formulas concerning jointly dependent variable seem to be satisfied. However we realise that in such complicated environment processes the interaction effects play an important role. So that, for the further works, the canonical and path analysis should be recommended to determine the main and simple effects as well as the relations between interaction effects.

ACKNOWLEDGMENTS

The autors would like to thank Prof.Dr.Wojciech Bychawski from the Institute of Geodesy and Cartography in Warsaw for advising the statistical analysis and Dr.Zbigniew Bochenek for image processing.

REFERENCES

Dmyterko, E., 1990: A method of the assessment of tree stand damage on the basis of the estimation of assimilation apparatus and tree crowns. III ad hoc FAO/ECE Meeting of experts on the practical application of satellite sensing for forest damage assessment, held in Sosnowka-Poland, May 28–30, 1990, 5 p.

Dmyterko, E., 1991: Monitoring des Einflusses der Luftver schmutzung mittels "Forsteinrichtungs-methode" auf die standige Probeflche. IUFRO and ICP-Forest workshop on monitoring, held in Prachatice-Czechoslovakia.

Grzyb, M. and Dmyterko, E., 1991: Guidlines principles of ground forest inventory within the European Experiment on the Use of Satellite Sensing to Forest Damage Assessment. Forest Research Institute in Warsaw, 20 p. (in Polish).

Polawski, Z. and Zawila-Niedzwiecki T., 1987: Assessment of the state of forest with the use of remote sensing in western Sudety Mountains. Sylwan No. 5, Polish Forest Society, pp. 49–60 (in Polish).

Rock, B.N., 1992: Minutes of the First Meeting of the Advisory Board of the Large Area Operational Experiment for Forest Damage Monitoring Using Satellite Remote Sensing, held in Prague-Czechoslovakia, January 8–9, 1992, 15 p.

UNEP-GRID, 1992: Large Area Operational Experiment for Forest Damage Monitoring in Europe Using Satellite Remote Sensing. A project plan drawn up by the Advisory Board in its second meeting in Warsaw, April 8–9, 1992, 8 p.

Zawila-Niedzwiecki, T., 1989: Satellite images for forest decline assessment. Proceedings of the International Conference and Workshop – Global Natural Resource Monitoring and Assessment: Preparing for the 21st Century, held in Venice-Italy, September 24–30, 1989, v. 1, pp. 473–478.

TABLES

Table 1. Exemples of linear regression results.

r	independent variable	dependent variable	description (aspect)
0.87	defoliation	TM1	NW
0.82–0.86	defoliation	TM1,2,3,4,5, PC1, Br	S
0.84	damage	TM1	SW
0.86	damage	TM1	NW
0.82	damage	TM1,3,5	S
0.85	damage	TM4,Br	S
0.81	damage	TM3	NW
0.86	damage	PC1	S
0.81	damage	PC1	N
0.81	damage	NDVI	N
0.83/0.84	discolouration	TM1,2	S,SW
0.83	discolouration	TM4,5,Br	N
0.87	discolouration	PC1	N

Table 2. Expressions and adjusted correlation coefficients (R2a) concerning the dependency of defoliation (Df), needles discolouration (Dc) and damage (Dm) indexes on TM derived spectral characteristics of the forest stands coveringdifferent slopes.

N-aspects:

(1) $Df=-5.99TM1 + 6.82TM3 + 0.64TM4 - 1.24TM5 + 0.35Age$ $R^2a=0.96$
(2) $Dc=-2.23TM1 + 2.58TM3 + 0.06Age$ $R^2a=0.87$
(3) $Dm=-0.18TM1 + 0.24TM3 + 0.02Age$ $R^2a=0.95$

NE-aspects:

(4) $Df=-5.34TM1 + 10.3TM2 - 5.41TM3 - 0.26TM4$ $R^2a=0.94$
(5) $Dc=-2.40TM1 + 2.55TM2 - 0.13TM4$ $R^2a=0.77$
(6) $Dm=-0.29TM1 + 0.59TM2 - 0.36TM3 - 0.01TM4$ $R^2a=0.94$

E-aspects:

(7) $Df=-5.56TM1 + 5.87TM2 - 0.27TM4 + 0.21Age$ $R^2a=0.88$
(8) $Dc=-1.93TM1 + 2.67TM3 - 0.22TM5 + 0.05Age$ $R^2a=0.55$
(9) $Dm=-0.28TM1 + 0.28TM2 - 0.01TM4 + 0.01Age$ $R^2a=0.90$

SE-aspects:

(10) $Df=17.14TM2 - 21.92TM3 - 1.07TM4 + 5.10TM7$ $R^2a=0.90$
(11) $Dc=-1.18TM1 - 1.93TM3 - 0.15TM4 + 0.09Age$ $R^2a=0.51$
(12) $Dm= 0.61TM2 - 0.73TM3 - 0.06TM4 + 0.11TM5$ $R^2a=0.91$

S-aspects:

(13) $Df=-5.19TM1 + 6.38TM2 - 0.46TM5$ $R^2a=0.97$
(14) $Dc=-1.98TM1 + 2.37TM2 - 0.32TM5$ $R^2a=0.83$
(15) $Dm=-0.31TM1 + 0.36TM2 - 0.01TM4$ $R^2a=0.97$

SW-aspects:
(16) $Df=17.41TM2-20.91TM3-1.12TM4+2.85TM7+0.24Age$ $R2a=0.91$
(17) $Dc=-1.88TM1+2.48TM2-0.23TM4$ $R2a=0.77$
(18) $Dm=0.90TM2-1.13TM3-0.05TM4+0.17TM7+0.01Age$ $R2a=0.95$

W-aspects:
(19) $Df=-8.33TM1+7.74TM2$ $R2a=0.93$
(20) $Dc=-8.22TM1+9.53TM3$ $R2a=0.53$
(21) $Dm=-0.42TM1+0.44TM2-0.01TM4$ $R2a=0.96$
NW-aspects:
(22) $Df=-8.68TM1+9.23TM2-1.81TM5+0.28Age$ $R2a=0.94$
(23) $Dc=0.58TM4-1.97TM5+2.40TM7$ $R2a=0.78$
(24) $Dm=0.06TM4-0.13TM5+0.02Age$ $R2a=0.95$

Table 3. Landsat TM classification results (1984–1990).

Class	1984	1990
Damaged stands	7259 ha	6194 ha
Dying and dead stands	2771 ha	2109 ha
Young and mixed stands	3425 ha	4411 ha
Old clear cuts	155 ha	922 ha
New clear cuts	1480 ha	733 ha
Dwarf mountain pine	2134 ha	2402 ha
Others (roads, gravel pits, rocks...)	2410 ha	2863 ha
	19634 ha	19634 ha

COMBINING FIELD SAMPLE PLOT, STRIP SURVEY, AND DIGITAL REMOTE SENSING DATA IN FOREST INVENTORY

Jouko Laasasenaho & Mark-Leo Waite
Associate professor and assistant researcher,
University of Helsinki, Dept. of Forest Resource Management

ABSTRACT

An attempt has been made to improve the efficiency of field work in forest inventory based on field sample plots and digital remote sensing data. In addition to plot data, strip segment data were registered in the field. These data consisted of boarder line and stand data of parallelograms along the inventory line.

Strip segment data can efficiently be used, e.g. for automatic segmentation of remotely sensed imagery, accurate localization of field sample plots, unbiased estimation of forest class proportions, and accurate estimation of stand characteristics for arbitrary compartments.

In this study, spectral features for each strip segment were derived and used as independent variables in neural networks predicting the means of segmentwise stand data.

Keywords: Forest inventory, strip survey, automatic segmentation, localization of sample plots, estimation of forest class proportions, estimation of forest characteristics, neural networks.

INTRODUCTION

In Finland, the use of digital satellite imagery in forest inventory has been studied for the past two decades. In practice it has, however, been utilizied only for some years in the National Forest Inventory (NFI), where the interpretation of satellite images makes up an important part in the calculation of inventory results for medium-sized areas, e.g. communes (c.f. Tomppo & Katila, 1991).

In addition to satellite image data, digital information about land-use, soil-types, roads, etc. are presently available for a large part of Finland. This makes it possible to interprete satellite images more accurately and to achieve more accurate forest inventory results, because e.g. the whole inventory area can be pre-stratified into meaningful classes.

Also, digital aerial photography and videography is becoming available for forest inventory purposes. Thus, estimation of forest characteristics for smaller units, e.g. compartments or even plots is already technically feasible.

In the current Finnish NFI, field sample plots are used to calculate inventory results for large areas and to aid in the interpretation of satellite imagery. These plots are usually relascope plots measured in clusters. Plot data are usually relatively accurate. However, relascope plots may represent only a small area in the forest and the data may change radically if the plot center is moved only a few meters. Thus, the coordinates of these sample plots must be known fairly accurately in order to achieve a high correlation between field and satellite imagery data. The accurate location of sample plots has, however, turned out to be rather problematic. Also, the use of relascope plots in small diameter stands may be questionable because of the small size of the plot compared to the size of satellite imagery pixels.

Although measuring plot data is fairly effective and intensive, trained field personal could be used effectively also in other ways. Also, if one wants to use modern modelling facilities, e.g. neural networks, present field measurement procedures may require reconsideration.

In this paper, the measuring of strip data, in addition to plot data, is suggested as a means to solve the above problems and to increase the effectiveness of field work. It is felt that trained forestry professionals can easily determine simple strip data which could prove most important in the interpretation of remotely sensed data.

OBJECTIVES

The main objectives of this study are to:

- Evaluate strip survey data as a data source in forest inventory based on field and remotely sensed data,
- Evaluate strip survey as a means of increasing the effectiveness of field work, and
- Evaluate neural networks (NN) as a modelling facility.

In this paper, mainly ideas concerning the use of strip data are presented. Actual results will be presented in forthcoming papers.

MATERIALS AND METHODS

Strip Structure

In this context a strip line is a line travelled in the field and a strip line point any point on a strip line.

A strip segment is defined as a parallelogram along a strip line where stand data are relatively homogeneous.

The right, left, top and bottom strip segment boarders are the bounding lines of a strip segment. The top and bottom boarders are also compartment boarders but the left and right boarders need not be. The top and bottom boarders consist of two line segments and the right and left boarders of one.

A strip line boarder point is a strip line point lying on the boarder of two successive strip segments and a strip segment center point a strip line point lying in the middle of a strip segment.

The structure of an inventory strip is illustrated in Fig. 1.

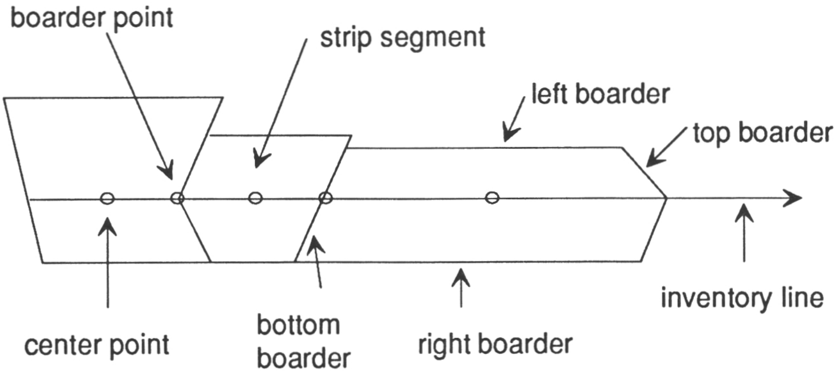


Figure 1. The structure of an inventory strip.

Study Area and Data Sources

The study area consists of a ca 200 ha forest lot near the the forest station of Hyytiälä (see Fig. 2).

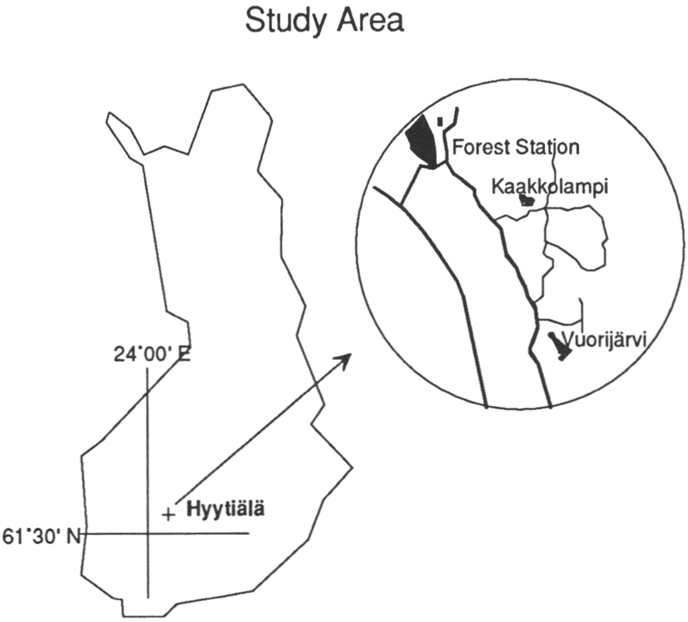


Figure 2. The location of the study area.

During a period of eight weeks in summer -89 ca 1000 relascope plots (BAF 2 m2/ha) were measured in this area. In June -92 four strips were additionally surveyed in two days. The total length, area, and number of strip segments of these strips amounted to ca 3200 m, 23 ha and 65 respectively.

Six resampled LandSat TM 25 m visible light and infra-red bands and three two-meter digital ortho-photo bands from summer -89 were also available for the study. From the two-meter ortho-photo, 4-, 8-, 16-, and 30-meter ortho-photos were derived by taking averages of n x n windows (n = 2, 4, 8 and 15 respectively).

A pancromatic image of the two-meter ortho-photo overlayed with road, lake, and strip segment line data is presented in Fig. 3.

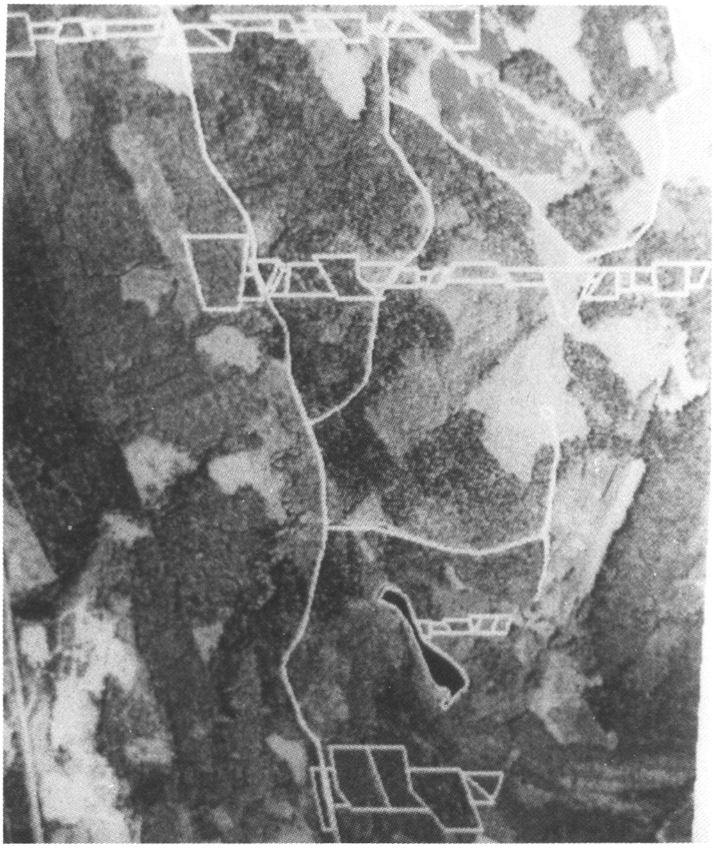


Figure 3. The two-meter ortho-photo with road, lake, and strip segment lines.

Strip Variables

During the strip survey the following geographic variables were registered in the field:

- Strip line starting point coordinates,
- Strip line compass direction,
- Distance from the starting point to the bottom segment boarder,
- Boarder line angles (2) at this point,
- Type of boarder (gradual/abrupt), and
- Distances to the left and right segment boarders (determined ocularly).

The following stand variables were also registered:

- Age/size class of the upper tree storey (DC),
- Basal-area of the upper tree storey (BA),
- Mean diameter of the upper tree storey (D),
- Mean height of the upper tree storey (H),
- Pine, spruce, and birch proportions of the upper tree storey (P%, S%, B%).

Stand variables were mainly determined ocularly.

From field survey data vector-formatted

- Strip line,
- Segment boarder and center point,
- Segment boarder line, and
- Segment polygon data

were derived using in-house PC programs. Image features for segment points and polygons were then derived also with in-house PC programs.

Neural Networks

Neural networks were selected as the analysis method for this study mainly because they are capable of

- Automatically detecting most complex relationships between sets of variables,
- Handling both continuous and categorical variables simultaneously, and
- Handling numerous independent and dependent variables simultaneously.

A neural network consists of a set of nodes which are arranged in layers. Typically there is an input and output layer and one or more intermediate layers. Nodes are connected to each other with weights. Output node values are derived by passing input node values through the network. Intermediate and output node values are calculated as

$o_j = f(\Sigma(w_{ij} * a_i))$, where

o_j = value of node j,
w_{ij} = weight connecting nodes i and j,
a_i = value of node i, and
f = some transformation function.

Connection weights are derived during a so-called training or learning phase. First all weights are initialised to random numbers. Then, for a specified number of iterations, a set of input values are presented to the net. The values are passed through the net and gradually transformed to output values. These values are compared to true output values and prediction errors are calculated. Prediction errors, gradient calculus methods, and learning rates are finally used to adjust the weights. This procedure is repeated until the output error converges.

The structure of a typical network used in this study is presented in Fig. 4 (page 10). The NeuralWorks Professional II/PLUS software package running on a SUN SPARC 670 MP server was used for the network analyses.

USE OF STRIP DATA

In this study it is proposed that, strip and remote sensing data be used together for the following four purposes:

- Correction of strip and sample plot locations,
- Automatic segmentation of forest areas,
- Estimation of forest class proportions, and
- Estimation of forest characteristics.

Correction of Strip and Sample Plot Locations

Strip segment and sample plot locations may be corrected with remote sensing data either visually or automatically. In visual correction, an iterative procedure, where first image data are displayed with strip segment boarder lines. If the segment lines seem to be misplaced, they can be corrected by modifying strip line starting points and line directions.

In automatic correction, the total within variance of strip segment pixel values are calculated for each strip using different starting points and line directions. The combination producing the minimum total variance is selected as the strip's true starting point and line direction.

Automatic Segmentation of Forest Areas

One way to segmentate a forest area is to

- Create a systematic grid of points,
- Identify those grid points, which are lying on stand boarders, and
- Connect these boarder points into lines and polygons.

Strip data and remote sensing data can be used in order to train neural networks for identifying stand boarder points e.g. in the following way.

First strip segment segment boarder and center points are used as NN observations. Then for each observation e.g. the following NN input data are derived:

- A maximum absolute difference, i.e. the maximum absolute difference between the nearest pixel value and the pixel values of an n x n neighbourhood,
- A Sobel value, which is calculated as

$\mathrm{sqrt}(x * x + y * y)$, where

$x = (c + 2 * f + i) - (a + 2 * d + g)$
$y = (g + 2 * h + i) - (a + 2 * b + c)$ and

a, b, c, d, f, g, h, and i are pixel values in the following 3 x 3 pixel neighbourhood

a b c
d e f
g h i,

- Relative tri-class frequencies, where first the pixel values i of an n x n pixel neighbourhood are classified into three class values c as follows:

$c = 0$ if $i < e - d$
$c = 1$ if $e - d < i < e + d$ and
$c = 2$ if $i > e + d$, where

e = nearest pixel value and
d = given threshold value.

Then relative pixel frequencies are calculated for each class.

NN output data are point types coded in the following way:

Point type	Coded value
No boarder	1 0 0
Gradual boarder	0 1 0
Abrupt boarder	0 0 1

Estimation of Forest Class Proportions

Czaplewski (1992) has shown that image-based estimation of forest class proportions can easily be quite biased. Tree shadows may, e.g. cause the underestimation of open forest proportions. However, if strip lines are measured in some statistical manner, they will provide unbiased estimates for forest class proportions.

Estimation of Forest Characteristics

It is evident that strip data and remote sensing data can be used with neural networks in order to estimate forest characteristics for arbitrary compartments or stands. One can also presume that standwise forest characteristics can be estimated more accurately than plotwise forest characteristics because

- There are more image data (pixels) available for each observation (stand/plot) and
- Stands are not as sensitive as plots to locational errors.

One can also assume that if one is interested in plotwise estimation, a guiding estimation of the surrounding stand would probably be of considerable help.

Strip data and remote sensing data can be used in order to train neural networks for estimating forest characteristics for stands, e.g. in the following way.

First strip segment polygons are used as NN observations. Then for each observation, e.g. the following NN input data are derived:

- Relative frequencies of requantified pixel values and/or
- Mean vector and co-variance matrix values.

NN output data are forest characteristics surveyed in the field.

Tables 1 and 2 illustrate some preliminary results on the correlation of NN estimates and field estimates for strip segments. The net used was of the so-called back-propagation type. The hyperbolic tangent transformation function and one intermediate layer of six nodes was found to be appropiate for the analyses. A diagram of a typical network used is presented in Fig. 4.

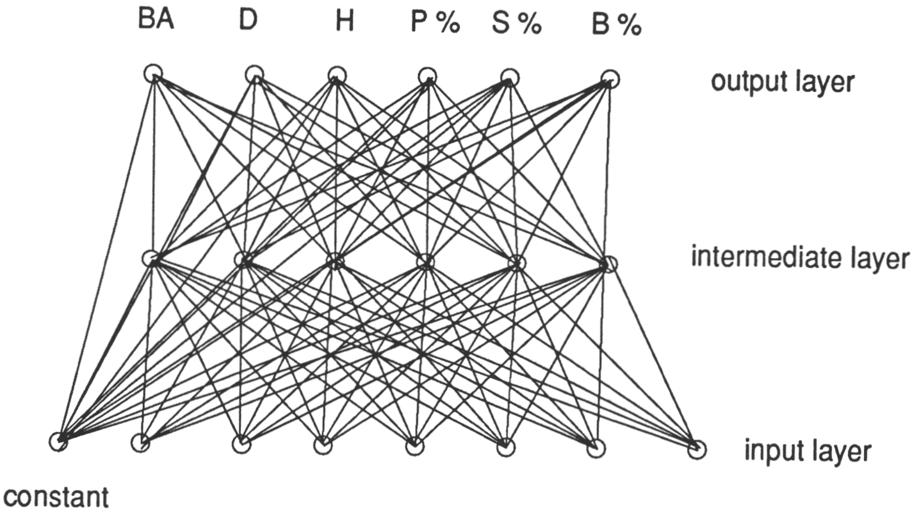


Figure 4. Structure of a typical network used for predicting forest characteristics.

Table 1. Correlation coefficients between NN and field estimates. Mean vectors and co-variance matrices as input data.

IMAGE	BA	D	H	P%	S%	B%	N
ORTHO2	0.792	0.920	0.926	0.969	0.966	0.932	54
ORTHO4	0.770	0.944	0.937	0.894	0.882	0.973	52
ORTHO8	0.823	0.915	0.928	0.963	0.960	0.916	52
ORTHO16	0.915	0.939	0.921	0.928	0.940	0.852	42
ORTHO30	0.850	0.819	0.857	0.915	0.911	0.962	42
TM	0.909	0.951	0.967	0.985	0.971	0.909	42

Table 2. Correlation coefficients between NN and field estimates. Requantified relative frequencies as input data.

IMAGE	BA	D	H	P%	S%	B%	N
ORTHO2	0.810	0.913	0.910	0.889	0.913	0.929	54
ORTHO4	0.825	0.878	0.919	0.905	0.907	0.929	52
ORTHO8	0.815	0.823	0.843	0.935	0.924	0.918	52
ORTHO16	0.840	0.903	0.904	0.879	0.868	0.887	42
ORTHO30	0.835	0.929	0.912	0.951	0.956	0.785	42
TM	0.889	0.935	0.944	0.956	0.931	0.922	42

All correlation coefficients are quite high and therefore the results are rather encouraging. One must, however, note that in these analyses the test data sets were identical to the training data sets and the training sets were quite small. Thus, the correlation coefficients are probably somewhat optimistic.

CONCLUSIONS

The study is presently in a preliminary phase. Both field measurements and calculation procedures could be developed in various ways. For example strip segment boarders could be delineated on paper in the field and digitized later.

Strip data can be used for both compartmentwise estimation and to improve plotwise estimation. They can also be used to remove bias in the estimation of forest classes and to compensate GPS-equipment.

Present unsolved key questions are:

- What and how strip stand variables should be determined in the field,
- How does estimation accuracy depend on the number of segments and number of plots,
- What is the optimal pixel size for the correction of plot and strip line locations,
- What is the optimal pixel size for automatic segmentation,
- What are the optimal plot and pixel sizes for plotwise/compartmentwise estimation, and
- How much can plotwise estimation be improved using compartmentwise data derived from strip data.

Calculation procedures depend largely on what and how field measurements have been carried out. However, neural networks seem to offer numerous possibilities during the calculation phases.

ACKNOWLEDGEMENTS

Forestry student Jorma Karjalainen provided valuable help in the final word processing phase.

REFERENCES

Czaplewski, Raymond L. 1992. Misclassification bias in areal estimates. *Photogrammetric engineering and remote sensing. Vol. 58, No 2, February 1992, pp. 189-192.*

Tomppo Erkki and Katila Matti. 1991. Satellite image-based National Forest Inventory of Finland - First large area results. Proceedings in the European collaborative programme workshop "Remote sensing for forestry applications". November 13-15, 1990, Copenhagen, Denmark.

FOREST CLASSIFICATION BASED ON SAMPLING AND MEASUREMENTS

Simo Poso
University of Helsinki
Helsinki, Finland

ABSTRACT

Area classification is an important part of forest inventory. For example, tropical forest inventories have usually resulted in little more than area statistics of different classes.

Area classification by ocular judgement is inexpensive and therefore attractive but are subject to the limitations of personal judgements (subjectivity and bias) and to the difficulty of defining the classes in a common standardised format.

This paper introduces an alternative approach to subjective pre-classification, that of post-classification based on measurements. This approach avoids many problems associated with area classification.

Keywords: Area classification, forest inventory, remote sensing, two-phase sampling

INTRODUCTION

Forest inventory and monitoring is usually based on the assumption that the land consists of land units which are more or less homogeneous in relation to land qualities and land characteristics and which can be demarcated on a map (cf. FAO 1984). The term land mapping unit has been used in the FAO as a synonym for land unit.

According to Davis and Johnson (1987), a land-type classification describes parcels or types of land by location, timber size, stocking, species, soil, slope, and other land attributes. "Stand types organise the land of a forest into classes that are homogeneous with regard to some basic land characteristics in order to predict timber yields and other responses of the land to treatments with confidence" (Davis and Johnson 1987).

Delineation of land into parcels is problematic when applying specific rules of pre-classification. The transition between neighbouring parcels may be diffuse resulting in subjectivity in the delineation of borderlines. The distribution of land into different classes is sensitive also to the size of parcels. The larger the parcels are delineated, the greater proportion the average classes tend to get whereas the uncommon classes tend to become even more rare.

Another problem in the application of the parcel technique for classification is flexibility. When classes are fixed they can not easily be changed to meet new requirements. Thus, when the purpose is to monitore changes, one may be stuck with an old and a less than ideal classification. According to Lund (1986), "definitions, classifications and measurements require standardization, but to encourage innovativeness, flexibility in how those standards are met should be allowed".

An alternative approach to pre-classification is sample-based post-classification. Together with remote sensing, it may offer solutions to the problems associated with pre-classification.

Systematic dot grids allow the estimation of areas efficiently. Kleinn and Pelz (1992) studied this efficiency by simulation on the basis of different forest cover maps. They found that simple patterns are estimated more precisely than more complicated patterns. They also found that the estimate of forest area is very sensitive to the definition used and the spatial pattern of the forest. If definitions change over time, or if different inventories are being compared, the results may not be very meaningful. One solution would be to avoid all pre-classifications and to use measurable tree– and stand– variables as a basis of classification. This paper describes post-classification methodology for forest inventory and monitoring based on the use of a systematic grid sample.

SAMPLE-BASED AREA POST-CLASSIFICATION

In order to design an area inventory, one should start with a definition of the population. For practical reasons, the population should be defined in accordance with the sampling design.

Here, it is assumed that the whole area is divided into squares of equal size and each square is represented by a plot. If the size of squares is made small, the number of plots becomes high. Assume that the total number of plots is N and the number of plots belonging to area class j is Nj. Then, the true proportion of class j, P_j, can be defined as

(1) $P_j = N_j/N$.

Correspondingly, the estimator for P_j is:

(2) pj = nj/n, where

nj = the number of sample units falling to class j and
n = the number of all sample units.

The sample units may be fairly small and thus easily measured in the field. Area classes in the field can be defined on the basis of measurements rather than ocular estimation. In other words, the classes are a function of measurements and not subjective estimations, i.e.:

(3) $y_i = f_i(x)$, where
y_i = class estimate through classification rule f_i.
x = variables measured in forest inventory and used as factors for classification.

The classes are not necessarily fixed beforehand but can be defined according to needs. For example, it is easy to define forest land on the basis of crown coverage with a minimum value of 10 or 20 %.

MEASUREMENT OF AREA CLASS IN THE FIELD

It is important to be able to say exactly how the area classes will be determined in the field. Assume that our sample unit is a circular plot 10 m in radius and that the classification-object is forest. The list of variables that could be used for post-classification may include:

- land suitability
- soil properties,
- topography,
- volume of the growing stock,
- age of the growing stock,
- mean height of the growing stock,

- crown cover,
- age, and
- tree species distribution.

The application of geographic information systems (GIS) could be very helpful in estimating some factors such as topography, accessibility, and demand for specific land uses.

Direct measurements give information about the actual state or situation on the sample unit. In addition, it may be desirable to get information about potential or future state. For example, a young forest stand may have a crown cover of 5 %, but one could estimate a potential value of 50 % when the stand reaches maturity. According to the potential value, the sample unit would be classified into forest land even though the actual crown cover does not yet fulfil the minimum requirement of this class.

The above example refers to the fact that not only direct but also indirect measurements, transformed variables, are needed for classification. This means that one part of the classification procedure consists of transformation functions, which can be expressed as:

(4) $x_i = f_i(x')$, where
x_i = transformed field variable i,
f_i = transformation function for x_i, and
x' = actually measured field variables.

It should be noted that classification can depend on the sampling design, especially on the size and form of the sample unit. For example, assume that instead of a small circular plot we use a large circular or square plot (Fig. 1). The classes which are rare and exist in small patches tend to become underestimated when large sample units are applied.

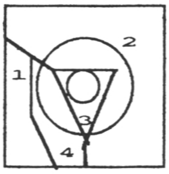


Figure 1. Map including four parcels and two alternative circular sample plots of different sizes.

Assume that the square area includes four different classes. The smaller circular plot falls almost totally into class 3 and the larger mostly into class 2. Because of the tendency to classify the sample unit on the basis of average (mode or median) coverage, using the larger plot would classify the sample unit into class 2 whereas using the smaller plot would classify the sample unit into class 3. An alternative and more accurate technique would have been to divide the sample unit into different classes. This, however, is not always easy because the borderlines between the parcels are ambiguous.

After the field measurements and basic analyses in the office have been made, we could have the following data groups for each field plot:

- variables measured directly,
- variables measured indirectly,
- rules for classification,
- results of classification.

The rules for classification need not be applied in the field but performed later in the office.

APPLICATION OF REMOTE SENSING

The quality of area classification depends greatly on the intensity of sampling. Sampling in the field is rarely intensive enough. The problem can be solved, to some extent, by applying remote sensing. For example, two-phase sample for stratification can be applied to make the sample intensive enough for a feasible area classification (Jaakkola et al. 1988).

By using two-phase sampling together with satellite imagery the intensity of the first phase sampling can be adjusted easily according to needs. In Finnish applications, it has been common to use an intensity of one plot per 25 m x 25 m. Each first phase plot can be supplied with estimates of all the data regarded as necessary based on the second phase measurements made in the field. Each first phase plot can then be classified by applying the same kind of classification functions as given in Eq. 3.

The application of two-phase sampling results in a sample which is, in a formal sense, analogous with a field sample of equal intensity. The only difference is that the two-phase sampling provides forest stand estimates, and hence, class estimates, with less reliability than possible for plots measured in the field.

COMPARISON OF MAP AND SAMPLE BASED CLASSIFICATION TECHNIQUES

One traditional technique for forest inventory and land classification is to delineate land units into homogeneous parcels on the map. Each parcel can then be measured for the surface area. If the borderlines are accurate, the area estimates will also be accurate. A problem with this map-based technique is the subjectivity in the delineation of the boundaries between neighbouring parcels as well as in its fairly high costs.

In the case of the two-phase sampling described above, the intensity of the first phase sample can be adjusted arbitrarily. If the distance from a plot to another is 25 m, the intensity is 16 units per a hectare, i.e., one plot corresponds to 0.0625 hectares. Accordingly, every parcel of land can be classified on the basis of those units falling on the parcel. It may be that the parcel is not homogeneous in relation to the class. In this case one must decide how to display the result. It is possible to use the mode, median, mean or distribution of units into different classes. This means that we do not need to assume the parcels to be homogeneous in relation to the class-specifications, as is commonly assumed with the mapping technique.

The map-based technique requires rules for pre-classification, otherwise delineation would not be sensible. The sample-based technique, on the contrary, is well-suited to post-classification.

CONCLUSIONS

The principle of map-based pre-classification of inventory area has severe problems. Consequently, post-classification based on objective measurements and classification functions becomes attractive. Once every sample plot can be located, the classification can be controlled fairly well for accuracy. Post-classification is scientifically sound; each plot can be checked and remeasured and the accuracy of the whole method can be determined.

If the plot intensity is high (e.g. 25 m by 25 m), the post-classification method described above is also suitable for management planning with in-place information. Sufficient intensity of data is possible through the advanced use of remote sensing and the benefits of geographic information systems are easily adopted.

There has been considerable interest in building a standardised classification system for national and regional forest inventories for world-wide use but, unfortunately, such a classification system is very difficult and perhaps impossible to attain. Specific problems are introduced by the need for successive multi-purpose inventories, monitoring of changes, and data up-dating.

The post-classification offers a usable basis for solving the standardisation problems associated with land classification.

REFERENCES

Cunia, T. 1978: The objectives and methodology of national forest inventory systems.Joint meeting of IUFRO Groups S4.02 and S4.04. Bukarest.

Davis, L.S. and Johnson,K.N. 1986. Forest management. Third Edition. McGraw-Hill Book Company. 790 p.

FAO. 1984: Land evaluation for forestry. *Forestry Paper* 48. Rome.121 p.

Jaakkola,S. Poso, S. and Skråmo, G. 1988: Satellite Remote Sensing for Forest Inventory Experiences in the Nordic Countries. *Scand.J.For.Res.* 3:545–567.

Kleinn, C. and Pelz,D. 1992: Forest area estimates: Sampling error and classification problems. Proceedings of the IUFRO S4.02.05: Remote sensing and permanent plot techniques for world forest monitoring, Pattaya, Thailand. p. 143–147.

Lund, G. 1986: A Primer on Integrating Resource Inventories. *United States Department of Agriculture. Forest Survey. General Technical Report* WO-49.

Acknowledgment:

Ph.D. Michael Starr has checked the English and edited the text with a critical eye.

MODERATORS' SUMMARIES ON DIFFERENT SESSIONS

NATIONAL FOREST INVENTORIES

Joe J. Lowe

After the theme speaker's comprehensive overview there were eleven other papers, which can be considered in three groups.

Established national inventories based on periodic measurement of sample plots were well described. No two inventories are identical, and it was interesting to see the differences, in part for reasons of legislation and organization.

A national inventory that combines autonomous regional inventories was described. A similar approach is used with national data for the Global Forest Assessment.

The third group described situations where national inventories have not yet been fully developed. Major problems are faced by countries with complex biological and social situations, with many agencies involved, and without adequate funds.

Despite differences between countries, it is possible to summarize the key topics. National inventories must increasingly deal with more than questions about wood supply. They must consider holistic forest ecosystems and their distribution, structure, health and productivity. There are many components, products and processes to consider in addition to the trees and commercial benefits. Not all the new concerns are fully defined, yet topics like "biodiversity", "biomass", "carbon cycle", "pollution" and "environmental impact" are urgent, with pressures to "monitor" the situation.

The costs and benefits of inventories must be balanced, yet speakers ranged in geographic detail from local forest management to continental views. Technical developments were mentioned concerning many of the new categories of information. Better working techniques were described for data management, as well as the integration of ground surveys with remote sensing at various levels of resolution. Special problems to be overcome include the inventory of remote or cloudy areas and the loss of permanent sample plots. Improved technology is a continuing need.

Recommendations

1. *International evaluation of NFIs* was recommended by C. Scott. In the discussion it was felt that while this may be desirable scientifically and technically there would be problems of diplomacy. Meetings such as the Kotka conference of NFI experts do help the process.
2. *Another meeting like the Ilvessalo Symposium in not more than ten years time* was suggested by G. Lund. Agreed. It was felt that the time interval should not be longer due to the rate of technological change.
3. *Better access to NFI data, especially in the tropics,* was recommended by B. Rollet.

GLOBAL MONITORING OF FOREST RESOURCES

Klaus Janz

Introduction

In this session the following papers were presented: (1) K. Janz "National inventories serving global monitoring", (2) L. Sayn-Wittgenstein "Remote Sensing and World Forest Monitoring" and (3) T.J. Peck & A.V. Korotkov "The Results of the UN-ECE/FAO 1990 Forest Resource Assessment (Temperate Zone)". As an introduction the context was outlined as follows:

(1) The United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro in June this year has given renewed attention to forest resources assessment. The role of such assessments for long term planning, for evaluating effects and for rectifying inadequacies has been emphasized in chapter 11 of Agenda 21.
(2) The global forest resources assessment carried out by FAO/ECE, Geneva and FAO, Rome will soon be completed. An interesting phase of preparing the next assessment has been initiated. Imminent events are (i) a UNEP/FAO meeting of experts on the inclusion of environmental aspects in future forest resources assessments to be held in Nairobi, Kenya, in December 1992 and (ii) a FINNIDA/FAO/ECE meeting of experts on general aspects of forest resources assessments to be held in Kotka, Finland in May 1993.
(3) A review in April 1992 of the FAO Forest Resources Assessment 1990 recommended a shift in emphasis in forthcoming global assessments towards country capacity building. Ideas as to how this can be done are presently taking form and were exposed in Mr. Janz' presentation.

National Inventories Serving Global Monitoring

Global inventories based on an aggregation of national data require a common framework of definitions and classifications as well as completeness. None of these conditions is readily fulfilled.

National inventories serve national purposes. On this level there is a great diversity of planning situations in which inventory information is needed. Hence it is natural that definitions and classifications differ between countries. International organizations have a role in establishing common standards to be applied in forest inventories to the extent suitable and possible.

For future tropical forest resources assessments of FAO a shift in emphasis has been recommended towards country capacity building. This should strengthen the capability of countries to (i) collect reliable information, well integrated in their planning processes and (ii) produce reliable information for global assessments. The idea is taking form to promote country capacity building in sub-regional workshops. In these the usefulness of forest resources information on the national and local level for planning, evaluating effects and rectifying inadequacies should be demonstrated. Sound methods for data collection and archiving should be identified and spread.

Remote Sensing and World Forest Monitoring

In future years there will be a great increase in demand for global forest monitoring, and much of this new demand will be for environmental information. As the interest and understanding of the importance of the global environment increases both the general public and the international community will demand information on the state of the environment. Much of this newly required information can be best supplied by remote sensing.

Future years will see an increase in the number and capability of remote sensing satellites. Particularly important developments will be the advent of radar satellites, the use of geographic information systems in combination with remote sensing and the development of more efficient and user-friendly technologies for the management of remote sensing data.

The Results of the UN-ECE/FAO 1990 Forest Resource Assessment (Temperate Zone)

The geographic coverage of the assessment includes Europe, the former USSR, North America, Japan, Australia and New Zealand.

The assessment is based on national replies to a detailed enquiry and consists of two parts, (1) general forest resources information and (2) benefits and functions of the forest. National correspondents have played an important role in collecting and verifying information.

One of the main findings that is common to most of the countries included is the continued expansion of the forest resource. The assessment has also revealed the increasing relative and absolute importance of the non-wood functions of the forest in the region.

Problems related to forest damage and threats to the forest ecosystems of the temperate zones continue to be analyzed in specific UN-ECE and FAO working groups. They have not been part of the present assessment.

MONITORING FOREST HEALTH

James T. Bones

Monitoring denotes repeated measurements or estimates of key attributes that indicate the changing condition of the trees that makeup the forest. It is implied that a standard of health is set from which all proceeding measurements are compared. Tree condition is not effected by national or international boundaries, but rather by pathogens, insects, pollution levels, or other physical or chemical factors.

Dr. Söderberg describes the evolution of forest health monitoring as conducted by the Swedish National Forest Inventory. During their entire history they have monitored tree condition, but only recently have they initiated Forest Damage Inventories in cooperation with the European ICP-Forests Program. At this point many indicators of health are being collected, but future analyses and comparisons must be carried out before the critical indicators of tree and forest health can be identified. He reports that such new technology as GPS and GIS will be future aids in the analysis process.

Dr. Scott et al. reports on the forest health monitoring program that is developing in the United States. New England was a developmental testing ground for design and procedures that were developed jointly by the USDA-Forest Service and Environmental Protection Agency in partnership with the State Foresters. They report on development of a sampling grid, field plot design, and identify attributes that are currently being measured. In future years, it is expected that the detection monitoring plots will be extended to include every State in the United States.

LaBau reports on cooperation between countries that makeup the boreal forest region; including Russia (CIS), Canada, Scandinavia, and the United States. He lists indicators of health that have been agreed upon by some of these Nations and groups them in four general categories; stand changes, soil characteristics, tree changes, and other ancillary data.

Definitions, standards, and techniques of monitoring are being developed intependently by many Nations. This presents a problem when global statistics are required. Scientists hope that International Organizations will provide leadership in coordinating the development of a common set of statistics.

TREE AND STAND MODELS IN FOREST INVENTORY

Harold E. Burkhart

In addition to an introductory paper by Burkhart aimed at giving an overview of tree and stand models in forest inventory, a session consisting of seven presentations on the topic was held. The purpose of this report is to review the topics presented at the modelling session, to state conclusions that might be drawn from the material presented, and to give recommendations for future work in this area.

The seven presentations can be grouped into three broad categories: (1) quantifying tree stems, (2) developing data bases, and (3) estimating precision. While estimation of the contents of the boles of standing trees is one of the oldest and most investigated problems of forest mensuration, it is interesting to note that four of the seven presentations dealt with this subject. Quantifying contents of standing trees is a critical and challenging modelling problem. In typical forest inventory work the contents of tree boles are not measured directly. Rather easily measured tree attributes, such as diameter at breast height and total tree height, are measured, and the relationship between the measured attributes and tree volume or weight is modelled. Because the expansion factors involved in most inventories are large, even small biases in the tree volume function can create large errors in the overall estimates. Hence the modelling of tree stems remains an area for continued effort at improvement and refinement. Furthermore estimates of overall volume are often not sufficient. Estimates of volume and quality by product classes are generally desired. In addition to traditional volume units, estimates of weight of tree stems, and often of branches and foliage, are also frequently required.

Papers presented in this session addressed many important aspects of quantifying tree-stem relationships. Kaufmann discussed bias in the tree volume function used in the first Swiss National Forest Inventory and an attempt to improve the volume function. His analysis involved adding a predictor variable (diameter at 7 m height) to the volume function (that is, tree volume was expressed as a function of diameter at breast height, total tree height, and diameter at 7 m height). The assessment of stem quality in standing trees in an inventory, coupled with a dynamic programming algorithm to simulate bucking of the stems to estimate the yield of log-products, was described by Goulding et al. This system, which has been widely used in New Zealand, has recently been upgraded and implemented on personal computers. Veiga reviewed regression models developed to predict the dry weight (biomass) of *Eucalyptus* and *Pinus* tree species in Brazil. Equations for estimating weight of branches and foliage, as well as for various portions of the tree stem, are included. Gregoire *et al.* presented two-stage and three-stage sampling strategies to estimate aggregate bole volume, thus circumventing problems with bias in tree volume functions. These authors derive unbiased estimators for the variance of the two-stage and the three-stage estimators.

Data bases for tree and stand modelling in Finland were reviewed by Mielikäinen and Gustavsen. Sample plots from inventories and from silvicultural experiments are important sources of empirical data for modelling. A landscape approach to developing data bases for forest management was advocated by Gromtsev and Golubev. These authors concluded that geo-ecological concepts can be useful in development of forest inventory systems.

On the topic of estimating precision, Kangas presented estimators for the standard errors of systematic cluster sampling. Model-based estimators were compared to approximations developed for the classical estimators approach.

From the information presented in the session on "Tree and Stand Models in Forest Inventory," and the discussion that followed, certain conclusions can be drawn and recommendations can be formulated. Namely:

1. Estimation of contents of tree stems continues to be a problem of concern. Participants in this session agreed that methods to quantify tree stems must be flexible (i.e., provide estimates for any specified portion of the tree bole), include quality variables, and encompass all tree components (biomass).
2. Acquisition of appropriate data bases for modelling is essential. Tree and plot measurements from inventories and from silvicultural experiments will be essential for modelling purposes. It is important, however, that we develop a more complete understanding of how the sample design (selection probabilities) employed affects estimation and inference for regression relationships fitted to the data.
3. Estimation of statistical error is important. Systematic sampling is often employed in forest inventory work. Unfortunately there are no general estimators for the standard error of systematic samples. Thus work on appropriate methods to approximate the error in systematic samples (as well as to derive estimators for error in other types of sampling where estimators are not presently available) should be continued.

In summary, tree and stand models will continue to play an important role in forest inventory. Inventory and modelling activities must be integrated for maximum efficiency in providing information for forest management decisionmaking. Data from inventories are often used for modelling, but we need to develop an improved understanding of how the sample design affects regression analyses and inferences with the data. We must also insure that models developed are compatible with the inventory data with which they are to be applied.

INVENTORY DESIGNS WITH SPECIAL EMPHASIS ON REMOTE SENSING

Leo Sayn-Wittgenstein

This session included several descriptions of the succesful application of remote sensing in inventories designed to deal with specific regional problems (papers by Hamzah, Xian-Xiang and Zawila-Niedzwiecki et al.). Other papers brought new information on tree species and forest types about which the international forest inventory/remote sensing community has only limited information (Danilin, Zobeiry), along with proposals for sampling design and analysis (Laasasenaho and Waite) and ideas on the problem of area classification (Poso).

Khali Aziz Hamzah described the use of state-of-the-art remote sensing methods in a survey of Malaysia's mangrove forests. The discussion which followed illustrated the enormous interest that can be generated for specific, regional forestry problems; it would have been easy to organize, on the spot, a follow-up symposium on mangrove forests.

Xian-Xiang's paper, presented by Guangxing Wang, described the use of aerial photography and satellite imagery in monitoring forests in China. The results included excellent maps based on interpreted satellite images. Forest monitoring was also the subject of the presentation by Zawila-Niedzwiecki and his coauthors. The area investigated was the Polish part of the Sudety Mountains, one of the most polluted regions of the world. Remote sensing, combined with a geographic information system, was used to monitor environmental damage and to provide a basis for action.

Danilin, from the Laboratory of Forest Morphology in Krasnoyarsk, presented equations and statistics on *Larix sibirica*, while Zobeiry laid out the forest inventory program and the potential for remote sensing offered by the oak forests of Iran. Both presentations bring to mind the advantages of using IUFRO to promote the use of common standards and procedures in collecting new forest inventory and biomass statistics. The international forest inventory community has relatively little information on Siberian larch and on the oaks of Iran and there would be significant mutual benefits in international cooperation in planning the collection of new data.

Laasasenaho and Waite described methods for combining field plot and strip surveys with digital remote sensing data and presented the advantages of this approach in the analysis of satellite data. Finally, Poso argued for a change in the method of area classification, replacing subjective classification with objective measurement. One can only hope that the IUFRO Forest Inventory Working Group will have the opportunity to follow up in more detail on his stimulating ideas.

PARTICIPANTS

Juri Agapov
North-Western Forest
Management Enterprise
Ul. Koli Tomchaka D. 16
196084 PETERSBURG
Russia
Anne Ahti
Forest Research Institute
Unioninkatu 40 A
00170 HELSINKI
Finland
Oleg Atroschenko
Belorussian Inst. of Technology
Dept. of Forest Inventory
Sverdlowsk street 13 A
220630 MINSK
Rep. of Belorussia
Peter Bachmann
Forest Inventory and Planning
ETH-Zentrum
HG F 18.1
CH-8092 ZÜRICH
Switzerland
James Bones
USDA Forest Service
FIERR
P.O.BOX 96090
WASHINGTON, DC 20090-6090
USA
Pirjo Brace
P.O.BOX 24 (Unioninkatu 40 B)
00014 UNIVERSITY OF HELSINKI
Finland
Brian V. Bredenkamp
University of Stellenbosch
Dept. of Forest Science
P/Bag 5018
STELLENBOSCH 7599
South Africa
Harold E. Burkhart
Virginia Polytechn. Institute
and State University
Department of Forestry
BLACKSBURG, VA 24061-0324
USA
Igor Danilin
Institute of Forest
Russian Acad. of Sci.
Akademgorodok
660036 KRASNOYARSK
Russia
Tron Eid
Dept. of Forestry
Agric. Univ. of Norway
P.O.BOX 44
N-1432 AAS
Norway
Andreas Fitje
Dept. of Forestry
Agric. Univ. of Norway
P.O.BOX 44
N-1432 AAS
Norway
Christopher Goulding
Forest Research Institute
Private Bag 3020
ROTORUA
New Zealand
Timothy Gregoire
Virginia Polytechn. Institute
and State University
Department of Forestry
BLACKSBURG, VA 24061-0324
USA
Andrew Gromtsev
Academy of Sciences
Karelian Centre
Forest Institute
185610 PETROZAVODSK
Russia
Hans Gustavsen
Forest Research Institute
P.O.BOX 68
80101 JOENSUU
Finland
Markku Halinen
Tehdaspuu Oy
45101 KOUVOLA
Finland
Khali Aziz Hamzah
Forest Research Institute
52109 KUALA LUMPUR
Malaysia
Gunilla Holmberg
Karhutie 26 F
00800 HELSINKI
Finland
Viljo Holopainen
Piispankatu 2 A
70100 KUOPIO
Finland

Jari Hynynen
Forest Research Institute
Unioninkatu 40 A
00170 HELSINKI
Finland
Bjarne Häggman
Vuoriharjuntie 41
02340 ESPOO
Finland
Antti Ihalainen
Forest Research Institute
Unioninkatu 40 A
00170 HELSINKI
Finland
Klaus Janz
Forest Resources Division
FAO
Via delle terme di Caracalla
00100 ROME
Italy
Rüdiger Jensen
WSL
Zürcherstrasse 111
CH-8903 BIRMENSDORF
Switzerland
Annika Kangas
Forest Research Institute
P.O.BOX 68
80101 JOENSUU
Finland
Matti Katila
Forest Research Institute
Unioninkatu 40 A
00170 HELSINKI
Finland
Edgar Kaufmann
WSL
Zürcherstrasse 111
CH-8903 BIRMENSDORF
Switzerland
Eero Kemppi
National Board of Forestry
P.O.BOX 8016
96101 ROVANIEMI
Finland
Pasi Kiema
Forestry Field Station
Hyytiäläntie 124
35500 KORKEAKOSKI
Finland
Boonchana Klankamsorn
Royal Forest Department
Office of Secretary
Bangkhen
10900 BANGKOK
Thailand
Jyrki Koivuniemi
P.O.BOX 24 (Unioninkatu 40 B)
00014 UNIVERSITY OF HELSINKI
Finland
Sergei Kopeiko
State Association
Lesprojekt
Novoschermushkinskay str. 69
117877, GSP-7, MOSCOW
Russia
Kari Korhonen
Forest Research Institute
P.O.BOX 68
80101 JOENSUU
Finland
Alexander Korotkov
ECE/FAO Agric. and Timber Div.
Palais des Nations
CH-1211 GENEVE 10
Switzerland
Tuomo A. Kotimäki
Finnish Forest and Park Service
P.O.BOX 94
01301 VANTAA
Finland
Kullervo Kuusela
Forest Research Institute
Unioninkatu 40 A
00170 HELSINKI
Finland
Jouko Laasasenaho
P.O.BOX 24 (Unioninkatu 40 B)
00014 UNIVERSITY OF HELSINKI
Finland
Jim LaBau
USDA Forest Service
Forestry Sciences Lab.
201 East 9th Avenue, Suite 303
ANCHORAGE, AK 99501
USA
Kaj Lindh
Itä-Hämeen metsälautakunta
Vesijärvenkatu 9 D
15140 LAHTI
Finland
Joe J. Lowe
Forestry Canada
Petawawa National
Forestry Institute
Box 2000
CHALK R., ON K0J 1J0
Canada
Eero Lukkarinen
P.O.BOX 24 (Unioninkatu 40 B)
00014 UNIVERSITY OF HELSINKI
Finland

H. Gyde Lund
USDA Forest Service
FIERR
P.O.BOX 96090
WASHINGTON, DC 20090-6090
USA
Gerardo Mery
Forest Research Institute
P.O.BOX 37
00381 HELSINKI
Finland
Kari Mielikäinen
Forest Research Institute
Unioninkatu 40 A
00170 HELSINKI
Finland
Juhani Moilanen
Forest Research Institute
Unioninkatu 40 A
00170 HELSINKI
Finland
Kyoei Nishikawa
Forestry and Forest
Products Res. Institute
P.O.BOX 16
Tsukuba Norin Kenkyu
Danchinai
IBARAKI 305
Japan
Aarne Nyyssönen
P.O.BOX 24 (Unioninkatu 40 B)
00014 UNIVERSITY OF HELSINKI
Finland
Risto Ojansuu
Forest Research Institute
Unioninkatu 40 A
00170 HELSINKI
Finland
Erkki Oksanen
Forest Research Institute
Unioninkatu 40 A
00170 HELSINKI
Finland
Stephen Omule
B.C. Ministry of Forests
Inventory Branch
VICTORIA, BC V8W 3E7
Canada
Matti Palo
Forest Research Institute
P.O.BOX 37
00381 HELSINKI
Finland
Eljas Pohtila
Forest Research Institute
Unioninkatu 40 A
00170 HELSINKI
Finland
Michael Yaw Poku-Marboach
Forestry Department
Planning Branch
P.O.BOX 1457
KUMASI
Ghana
Simo Poso
P.O.BOX 24 (Unioninkatu 40 B)
00014 UNIVERSITY OF HELSINKI
Finland
Risto Päivinen
University of Joensuu
P.O.BOX 111
80101 JOENSUU
Finland
Bernard Rollet
15 rue Erard
F-75012 PARIS
France
Wladimir Sakovets
Academy of Sciences
Karelian Centre
Forest Institute
185610 PETROZAVODSK
Russia
Juha Salmi
National Board of Forestry
P.O.BOX 8016
96101 ROVANIEMI
Finland
Liisa Salmi
Forest Research Institute
Unioninkatu 40 A
00170 HELSINKI
Finland
Sakari Salminen
Forest Research Institute
Unioninkatu 40 A
00170 HELSINKI
Finland
Leo Sayn-Wittgenstein
CCRS-EMR
588 Booth Street
OTTAWA, ONT K1A 0Y7
Canada
Pierre Schram
CEPS/INSTED
1, rue de la Forêt
L-8065 BERTRENGE
Luxembourg

Charles Scott
USDA Forest Service
359 Main Rd
DELAWARE, OH 43015-9076
USA

Gustaf von Segebaden
Askvägen 30
S-75653 UPPSALA
Sweden

Risto Seppälä
Forest Research Institute
Unioninkatu 40 A
00170 HELSINKI
Finland

Yrjö Sevola
Forest Research Institute
P.O.BOX 38
00381 HELSINKI
Finland

Jouni Siipilehto
Forest Research Institute
P.O.BOX 18
01301 VANTAA
Finland

Markku Siitonen
Forest Research Institute
Unioninkatu 40 A
00170 HELSINKI
Finland

Ulf Söderberg
Swedish Univ. of Agric. Sciences
Dept. of Forest Survey
S-901 83 UMEÅ
Sweden

Giovanni Tabacchi
Istituto Sper. Assest.
Forestale Alpicoltura
Via Giordano 8
I-38050 VILLAZZANO
Italy

Songkram Thammincha
Faculty of Forestry
Kasetsart University
10903 BANGKOK
Thailand

Christian Tharaldsen
Norwegian Institute of
Land Inventory
P.O.BOX 115
N-1430 AAS
Norway

Erkki Tomppo
Forest Research Institute
Unioninkatu 40 A
00170 HELSINKI
Finland

Stein M. Tomter
Norwegian Institute of
Land Inventory
P.O.BOX 115
N-1430 AAS
Norway

Sauli Valkonen
Forest Research Institute
Unioninkatu 40 A
00170 HELSINKI
Finland

Lauri Valsta
Forest Research Institute
Unioninkatu 40 A
00170 HELSINKI
Finland

Ricardo Veiga
Dept. of Forest Sciences
FCA-UNESP
18600 BOTUCATU-SP
Brazil

Mark-Leo Waite
P.O.BOX 24 (Unioninkatu 40 B)
00014 UNIVERSITY OF HELSINKI
Finland

Guangxing Wang
P.O.BOX 24 (Unioninkatu 40 B)
00014 UNIVERSITY OF HELSINKI
Finland

Hannu Yli-Kojola
Forest Research Institute
Unioninkatu 40 A
00170 HELSINKI
Finland

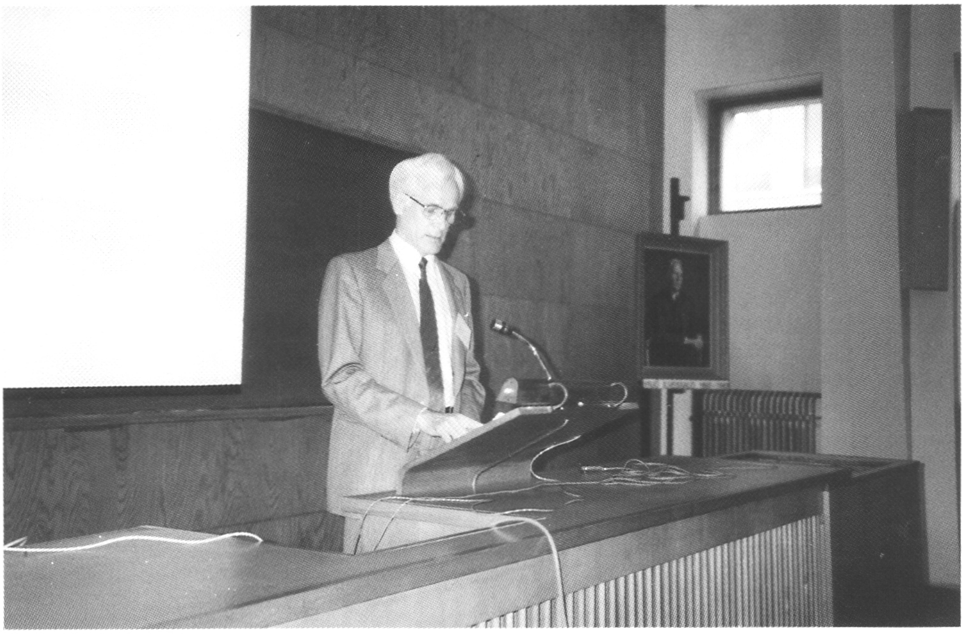
Xian Xiang You
Beijing Forestry University
P.O.BOX 120
BEIJING 100083
China

Tomasz Zawila-Niedzwiecki
Remote Sensing and
Spatial Inf. Centre
OPOLIS
00-950 WARSAW
Poland

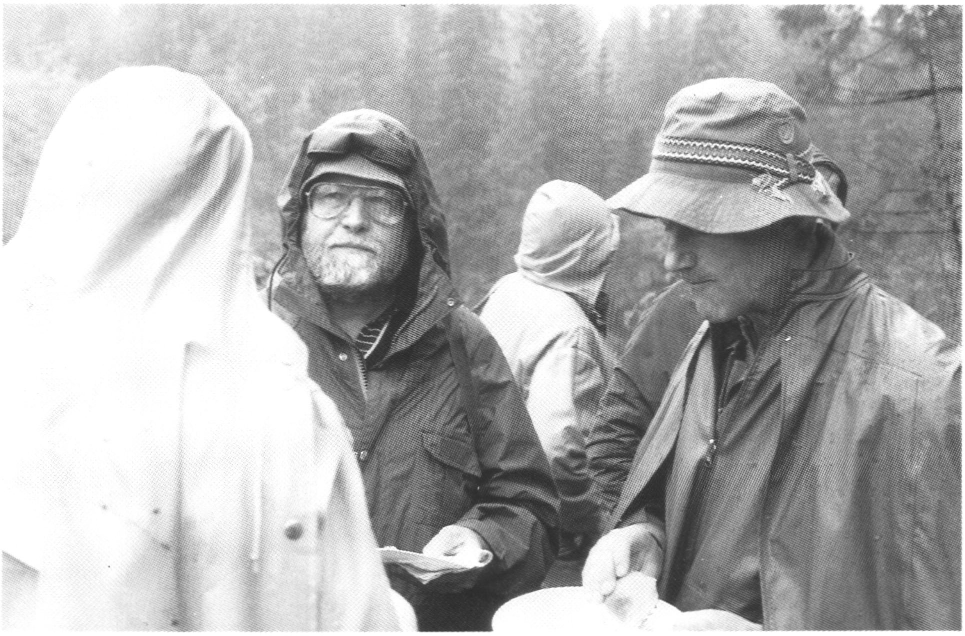
Mahmoud Zobeiry
University of Tehran
College of Natural Resources
KARADJ
Iran

PHOTOGRAPHS

Opening Session

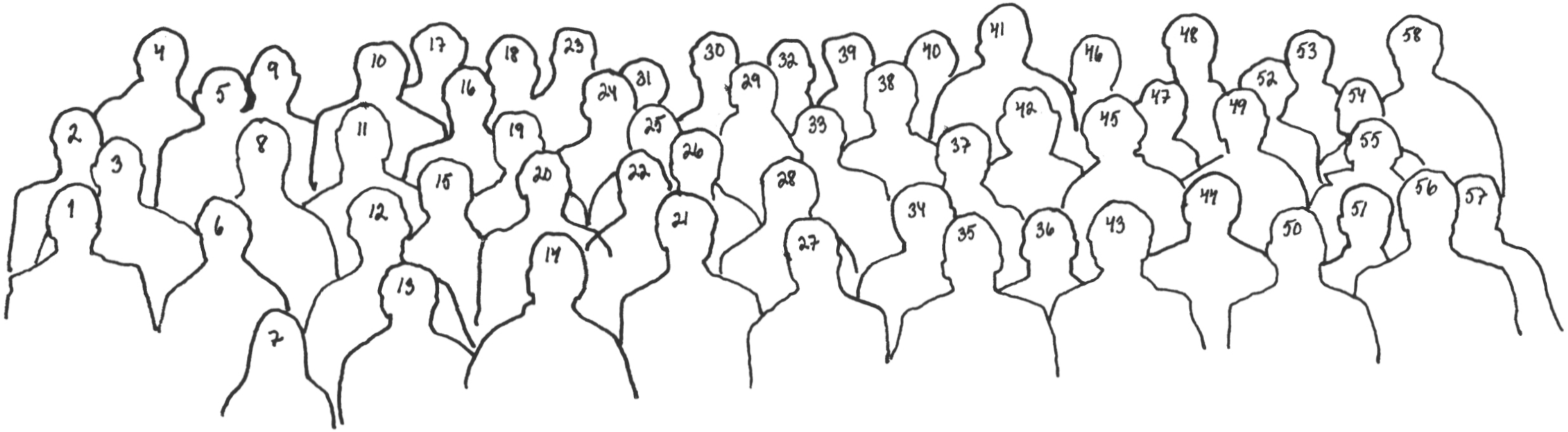


Excursions



Final Session

Secretaries



1. C. Goulding
2. B. Häggman
3. G. Lund
4. E. Tomppo
5. J. Bones
6. H.E. Burkhart
7. Katie Burkhart
8. T. Eid
9. V. Holopainen
10. A. Korotkov
11. R. Veiga
12.. K. Burkhart
13. B. Klankamsorn
14. S. Thammincha
15. W. Sakovets
16. R. Seppälä
17. P. Bachmann
18. J. Lowe
19. A. Gromtsev
20. M. Zobeiry
21. T. Gregoire
22. T. Zawila-Niedzwiecki
23. U. Söderberg
24. O. Atroschenko
25. K. Kuusela
26. S. Salminen
27. M. Poku-Marboah
28. S. Omule
29. K. Lindh
30. J. Hynynen
31. S. Tomter
32. A. Fitje
33. J. Agapov
34. B. Bredenkamp
35. K. Hamzah
36. K. Nishikawa
37. L. Sayn-Wittgenstein
38. I. Danilin
39. G. von Segebaden
40. A. Ihalainen
41. R. Jensen
42. L. Salmi
43. P. Schram
44. H. Yli-Kojola
45. J. Wiechard-Schram
46. K. Mielikäinen
47. B. Rollet
48. J. Laasasenaho
49. C. Scott
50. A. Nyyssönen
51. R. Päivinen
52. P. Brace
53. K. Janz
54. A. Ahti
55. E. Kaufmann
56. S. Poso
57. G. Tabacchi
58. C. Tharaldsen

Cover photograph:
An Example of a thematic map produced by the National Forest Inventory of Finland. Different colours refer to land use classes and the growing-stock volume. Stand boundaries based on a computer algorithm are also displayed.

Metsäntutkimuslaitoksen tiedonantoja 444
The Finnish Forest Research Institute. Research Papers 444

ISSN 0358-4283 ISBN 951-40-1267-4