REMOTE SENSING SYMPOSIUM

Proceedings of a Symposium sponsored by the
Ontario Ministry of Natural Resources
and the
Great Lakes Forest Research Centre
under the auspices of the
Canada-Ontario Joint Forestry Research Committee
Toronto, Ontario
22-25 October 1979

C. R. MATTICE, COORDINATOR

GREAT LAKES FOREST RESEARCH CENTRE

SAULT STE. MARIE, ONTARIO

COJFRC SYMPOSIUM PROCEEDINGS O-P-8

CANADIAN FORESTRY SERVICE

DEPARTMENT OF THE ENVIRONMENT

APRIL 1980

FOREWORD

The Canada-Ontario Joint Forestry Research Committee (COJFRC) is a federal-provincial group with representation from senior management of the Ontario Ministry of Natural Resources (OMNR), the Great Lakes Forest Research Centre and, more recently, the Canadian Wildlife Service and the Petawawa National Forestry Institute.

Members of COJFRC coordinate the planning and execution of forestry research programs at the Great Lakes Forest Research Centre and at OMNR's Ontario Forest Research Centre. In addition, COJFRC is directed to "coordinate the effective communication of the results of forest research programs to forest managers and administrators". It is in partial fulfilment of this latter requirement that COJFRC annually sponsors a symposium on some aspect of research that is of current concern to Ontario's forest managers.

The 1979 symposium, which dealt with remote sensing, was held in Toronto from October 22 to 25. Although the topic was chosen primarily in response to the demands of forest managers for increasingly accurate and up-to-date information about the forest resource, it was the need to focus on the gap between present practice and technological capability in remote sensing which became important in developing the program. Equally important was the lack of research technology sufficiently well developed to be transferred to operational practice.

There were 146 delegates at the symposium, with 65% representing Ontario's forest managers and 7% representing forest industry. The remainder were drawn from the Canadian Forestry Service (7%), the remote sensing industry (6%), other provincial forestry services (5%), universities and colleges (4%) and interested individuals (6%). Of those affiliated with OMNR 90% were foresters and the remainder were involved in wildlife management, fire management and land use planning.

Participants were welcomed by J.H. Cayford, current COJFRC chairman, who spoke briefly on the background and purpose of the committee. As Director of the Great Lakes Forest Research Centre, he stated that the Centre was prepared to discuss greater involvement in remote sensing research in areas that are relevant to the current forestry program. The symposium was then opened officially by Dr. J.K. Reynolds, Deputy Minister of the Ontario Ministry of Natural Resources, who praised COJFRC for the unique and successful role it plays in coordinating federal-provincial forest research. He also gave his personal support to the aims and efforts of the Ontario Centre for Remote Sensing. In concluding the opening ceremonies, V. Zsilinszky, symposium chairman, drew attention to the need for more vigorous action to transfer remote sensing technology to forest managers, but warned that technology "outputs" were strongly dependent on user "inputs".

The technical program which followed consisted of 21 papers presented during five sessions. Included in the two-and-a-half day symposium was a tour of the Ontario Centre for Remote Sensing by 90 delegates and a panel discussion in which five panelists stated their views in response to the question, "Where do we go from here?", and responded to questions from the other delegates.

The organizing committee expresses its gratitude to all who contributed to the planning and organization of this symposium. Special thanks are extended to the many individuals who worked diligently behind the scenes and at the symposium itself to ensure its success.

TABLE OF CONTENTS

SESSION I

Why Remote Sensing for Resource Management?

SESSION II

Thematic Mapping

SESSION III

Forest Inventory and Data Base

(continued)

TABLE OF CONTENTS (concluded)

SESSION IV

Special Applications

SESSION V

Where Do We Go From Here?

INTRODUCTORY REMARKS

J.H. Cayford, Chairman[1]
Canada-Ontario Joint Forestry Research Committee

and

V.G. Zsilinszky, Chairman[2]
Technical Program

J.H. Cayford: "Good morning and welcome to the Remote Sensing Symposium which is sponsored by the Canada-Ontario Joint Forestry Research Committee, or COJFRC, as it is commonly called. This federal-provincial committee was established under a formal agreement between the respective Deputy Ministers. The purpose of the agreement is to ensure "that the fullest and most efficient use possible is made of the forestry research resources available in the Great Lakes Forest Research Centre and the Forest Research Branch of the Ontario Ministry of Natural Resources" (now the Ontario Forest Research Centre). The Committee is responsible for coordinating the planning and execution of forest research programs of the two research organizations, and for coordinating the effective communication of the results of forestry research programs to forest managers and administrators.

As one method of communicating the results of research, the Canada-Ontario Joint Forestry Research Committee, through the two research organizations, has sponsored an annual symposium since 1973. Topics discussed in past symposia include tree improvement, plantation establishment, and black spruce management. The primary objective of this symposium series is to bring together Ontario's practising foresters and researchers to participate in the evaluation of current priority forestry concerns.

This symposium differs from past symposia in that very few of the speakers are from either the Great Lakes Forest Research Centre or the Ontario Forest Research Centre. However, because of the importance of remote sensing and its potential application to many aspects of forest management, we have asked a number of remote sensing specialists from across Canada to speak to us over the next three days. We are indeed grateful to these people for agreeing to participate in the symposium.

---

[1] Director, Great Lakes Forest Research Centre, Department of the Environment, Canadian Forestry Service, Sault Ste. Marie, Ontario.

[2] Research Scientist, Ontario Centre for Remote Sensing, Ontario Ministry of Natural Resources, Toronto, Ontario.

I am also speaking to you today in my capacity as Director of the Great Lakes Forest Research Centre. This is the sixth consecutive symposium that I have attended and it is my pleasure to welcome all of you to the remote sensing seminar. At the same time I would like to convey my best wishes for a successful and informative session."

V.G. Zsilinszky: "As provincial cochairman, I wish to welcome you, ladies and gentlemen, and to introduce you to the members of the program committee. Mr. Charles Mattice, the federal cochairman, is a Forestry Officer with the Great Lakes Forest Research Centre in Sault Ste. Marie. Charlie's cooperation and hard work have made my job almost dispensable. David Bates, Supervisor of Applications at the Ontario Centre for Remote Sensing in Toronto, made arrangements for accommodations, social programs, technical exhibits, etc. Dr. Peter Kourtz, a Research Scientist at the Petawawa National Forestry Institute in Chalk River, made a major contribution to the planning of the symposium.

We would like to thank Mr. J.H. Cayford, Mr. W.K. Fullerton, and all the members of the Canada-Ontario Joint Forestry Research Committee for their wise choice of theme for this year's COJFRC symposium. Jim Cayford's personal guidance during the planning and preparation of the symposium is gratefully acknowledged. We also appreciate the tremendous efforts of the many unknown soldiers at the Ontario Centre for Remote Sensing, who photocopied papers, made arrangements for displays, provided screens and extension cords, and so on.

We are very grateful to Dr. J.K. Reynolds for his encouraging words this morning, and we trust that the program will indeed fulfill its purpose.

In this era of economic unrest, the resource manager must be assured that remote sensing is a cost-effective tool for planning and management. Much of the technology is readily applicable, and members of the remote sensing community have been introducing and transferring this technology to interested recipients on a regular basis. This process must continue and the technology must be exploited fully for both short-term and long-term benefits.

Potential users must recognize that without input there is no output. Remote sensing research and development depend to a large extent on the moral support of those who will use the technology and on their willingness to invest time, effort and money over the long term.

A symposium such as this is an excellent forum for communication among remote sensing specialists and users such as resource managers. The Program Committee has therefore structured the symposium so as to emphasize two-way communication by raising a basic question: "Why remote sensing for resource management?"

We shall begin this morning with four invited papers. The first three speakers will attempt to answer that question from the user's point of view, while the fourth speaker will present the viewpoint of a member of the remote sensing community.

Two background papers will follow this afternoon, and specific remote sensing applications will be discussed in subsequent sessions.

The final session on Thursday morning will be a panel discussion dealing with the question: "Where do we go from here?"

I am hopeful that this symposium will achieve what it is intended to achieve, and that when you leave on Thursday, ladies and gentlemen, you will feel that your time and money have been well spent."

SESSION I

Why Remote Sensing for Resource Management?

Chairman: V.G. Zsilinszky
Ontario Centre for Remote Sensing
Ontario Ministry of Natural Resources
Toronto, Ontario

WHY REMOTE SENSING IN FOREST MANAGEMENT?

J.F. Flowers, Regional Forester
North Central Region
Ontario Ministry of Natural Resources
Thunder Bay, Ontario

The author has worked with staff of the Ontario Centre for Remote Sensing to determine and develop techniques for the use of infrared color aerial photography in assessing the success of conifer regeneration in the boreal forest. He has also explored the use of LANDSAT imagery for forest inventory and other forest management purposes. This paper outlines achievements to date and stresses the need for applying these techniques on an operational scale, without further delay.

L'auteur a travaillé avec le personnel du Centre ontarien de télédétection pour définir et développer des techniques utilisant la photographie aérienne infrarouge en couleur pour évaluer le succès de la régénération des Conifères de la forêt boréale. Il a aussi exploré l'utilisation des images LANDSAT dans les inventaires forestiers et autres fins d'aménagement forestier. Cet article met en évidence les succès remportés jusqu'ici et souligne le besoin d'appliquer ces techniques sur une échelle opérationnelle sans plus tarder.

Remote sensing is essential for the efficient management of our forests. The use of remote sensing technology is not new to us; in fact, Ontario was the first Canadian province to use aerial photography to map and prepare a forest inventory of a large forest estate. Had the old system of mapping forest types from ground surveys been used we might not yet have a completed inventory. The ability to outline forest types on accurate topographical maps in large areas that would not be accessed for much of the first rotation made it possible to complete a provincial inventory in a fraction of the time required by previous techniques.

Even though we use aerial photographs in the day-to-day management of our forests we have not yet fully exploited even this comparatively primitive system of remote sensing. Victor Zsilinszky was instrumental in developing a practical system for the regular use of 35 mm cameras by our field staff in obtaining their own supplementary aerial photographs. This technique has permitted each district to obtain new photographs of any area as they require them. Up-to-date maps were placed in the hands of the local forest manager to permit better decision making and more accurate recording of physical changes in the forest landscape. Prior to this widespread use of aerial photography, most mapping was dependent upon comparatively inaccurate ground surveys with periodic updating by means of aerial photographs every 5 to 10 years.

There is plenty of scope for developing this system even further. To date we have used standard black and white photographs almost exclusively. Color, infrared and near red photographs have not been used to any extent on an operational level, although they have been used to a limited degree in tests.

Had senior professional staff in the Division of Forests exhibited greater interest, I expect we would have advanced much more rapidly by now in the operational use of these new technologies. It is difficult for a specialized unit to develop new approaches and techniques without the expressed interest of management as well as its moral and financial support.

The North Central Region has been working with the staff of the Ontario Centre for Remote Sensing for several years. We are interested in gaining a better understanding of the potential of all new technologies that have developed since the advent of the space age.

In particular, we have been exploring the operational potential for using infrared color film in supplementary aerial photography to assess the success of our conifer regeneration program. During the past two years staff of the Centre have tested their photographic and interpretive skills against the conventional ground assessment procedures. Their second report is now in my hands. The study was continued this past summer, but I have not yet received an updated report.

One objective of this study was to determine which was the most appropriate camera--35 or 70 mm--and which elevations and camera lens provided the best photographs for interpretation. Exposure proved to be critical to the production of good-quality images. The second-year photos were far superior to those of the first year. The 70 mm format proved to be the most appropriate although 35 mm is acceptable and will probably continue to be used. Various exposures and altitudes were tested with different lenses to provide photos of varying scales. The film is difficult to use, and specialists may be required for the purpose.

The three different scales tested were 1:22 900, 1:9 140, and 1:3 660. The smallest scale will permit general stratification for further assessment while the largest will permit sample plots to be measured for stocking of the conifer species. The photographs must, of course, be taken during the leaf-free times of the year so that only conifers appear on the film.

Staff of the Ontario Centre for Remote Sensing will explain in detail the results of the two-year trials and will indicate how this method might be used operationally for assessment of conifer regeneration. The prime objective of the trials was to develop a procedure that could be used easily by field staff.

Infrared color photographs can also be used to identify frost pockets in areas of successful regeneration. Once these pockets are identified the manager can change species or at the very least refrain from replanting areas doomed to failure. The photos can also be used to identify insect and disease damage. This technique, which will be discussed further in another session of the symposium, was used last fall in outlining a specific outbreak of spruce budworm in the Geraldton District. The maps were used in planning control measures.

We are beginning to identify uses for at least a few of the new sensing techniques and to apply these techniques in the field.

It is important that regular field staff be able to utilize any new techniques developed. They must be directly involved in their application, and not be dependent on specialists. That is not to say that they will not require special training, but once they are trained, they should be able to utilize the techniques on their own. I stressed the importance of this parameter when I asked staff of the Centre to explore and develop a system of regeneration assessment using infrared color film.

Forest management, to be effective on the scale required in Ontario, must have the most up-to-date tools possible at its disposal. Remote sensing technology is changing rapidly, and it has the potential for putting the planning and management of our forests on an equal footing with harvesting practices. Harvesting technology has developed dramatically during the past 25 years but other forest management procedures have virtually stood still. Canada has a dismal record in research and development--not in the initiation of concepts, where we are among the leaders in the world, but in our support for inventors and developers, who are invariably forced to go to other countries to have their ideas put into practice. Surely within our own province we can put forth the effort and resources necessary to bring our forest management practices up to the standard of those of other countries. The establishment of the Ontario Centre for Remote Sensing was a great step forward but we have failed to make the maximum use of its potential.

Another study, undertaken jointly by Lakehead University and the Ontario Centre for Remote Sensing, with financial assistance from the North Central Region, involved the use of thermography to map frost pockets and to identify scarified sites. An undergraduate thesis has been written by Allen V. Banner and a report will be published by the Ontario Centre for Remote Sensing.

The more sophisticated technology of satellite imagery is available to us as well, and has potential for use in forest management. However, decision making by forest managers is often hampered by a lack of up-to-date information on the vast resource areas for which they are responsible. I have often sat at meetings between government and industry where very serious long-range decisions are made. All too often we, the managers, have to say that we are not sure of our information because the inventory is 15 years old or the photographs are too old to be reliable. This is both embarrassing and unnecessary. From the little I have learned about the potential for use of LANDSAT imagery in forest management I am convinced that it can be the most powerful tool placed in our hands since the aerial photograph. Its value is far greater in North America than in Europe where the forest estates have been under intensive management for hundreds of years. It will probably be many more hundreds of years before the forest lands of Ontario are managed to the same degree. We will always have large areas that require constant updating of maps and identification of problems not readily discernible on the ground.

We must record accurately the land that has been taken out of production annually because of road building, flooding, etc., and the land that has changed status because of losses from cutting, fire, insects and disease. These are all items that can be documented by what we now consider conventional techniques. However, this approach requires considerable staff time. Our resources fall far short of those of virtually every other major country in the world that manages its forests. It is doubtful that we will ever reach the staffing level per unit area that some countries are now able to achieve.

I have worked with Dr. Simsek Pala over the last several years exploring the use of LANDSAT imagery for general forest inventory use. Unfortunately, in the past two years further development of an interpretive skill for the boreal forest, my main concern, has not had support from top management, but this appears to be changing now.

Work to date clearly indicates that at least some species can be delineated and mapped once the computer has been fed the proper information. Considerable field work is required to provide this information and to field check the results provided by the computer map. The first tests, made two years ago, were very promising. The precise degree to which species, particularly the same species with different ages and stocking, can be delineated accurately has not yet been defined. We need a full-scale study of the potential of this technique. I sincerely hope that the Forest Resources Group of the Ontario Ministry of Natural Resources will recognize this potential and make a major effort to develop it.

At the recent workshop on remote sensing in Edmonton, I was disappointed to learn that no work has been done on the development of LANDSAT imagery in recent years. I had hoped that by now the limitations for at least some of the obvious forestry uses suggested above would have been determined. A great deal of developmental study is required if we are to determine how, where, and when these new techniques can serve the forest manager effectively.

I believe that we must develop a new inventory system in Ontario that is largely dependent on the use and effective interpretation of LANDSAT imagery. I firmly believe that this is possible for the boreal forest at least. It is difficult to understand the general reluctance to explore such an option. There are certainly questions to be answered and problems to be solved, but we in Ontario could lead the way in the development of this technology. We have a great deal to gain by doing so.

I view remote sensing as one of the most exciting advances in technology since I became a forester 30 years ago. It disturbs me that neither top management nor field staff share my enthusiasm.

If any new technology is to be developed properly for operational use, a commitment is required on the part of top management. Once the decision is made it must be supported morally and financially, and adequate staff must be provided.

A new system, to become effective, requires the dedication of the staff involved, the recognition that there will be problems and setbacks, and the willingness to accept them without becoming discouraged. Clear goals must be set and constantly reviewed to ensure that they remain valid in view of the advances made. This will permit management to monitor progress and to know that the results will be of practical use.

Management may not be willing to support new concepts if the operational field staff appear not to be interested in them. It is important that all field managers and supervisors be kept up to date on the changing technologies and their potential value as management tools. With field support, top management will be more confident that the findings which are a result of considerable effort and expenditure will be put to practical use.

Some of my remarks may leave you with the impression that we have not been using remote sensing in Ontario at all. This is not the case. It has been used for specific projects and special trials but it has not moved forward to the degree it must if it is to become a tool of the management forester and not just a tool of the scientist or the remote sensing specialist.

If this conference succeeds in bringing about an increased interest in the use of remote sensing technology on the part of both field staff and senior management in Ontario then it will truly have been a success for Ontario, not just for those of us who are here today.

Discussion

There was considerable discussion about the need for improved communication between the "user and remote sensing communities". The current practice of OCRS of holding three-day seminars was criticized for concentrating too much on technique and not enough on basic questions about the application of the technology in forestry practice. In defence of the emphasis on training in the current seminar program, it was claimed that feedback from the Supplementary Aerial Photography Program revealed a substantial lack of knowledge and sophistication in remote sensing.

The point was also raised that any hope of using a combination of satellite imagery and conventional aerial photography must result from a commitment by senior management. In this regard the comment was made that considerable testing of the accuracy of information obtained from satellite imagery must precede its incorporation into an inventory program.

REMOTE SENSING IN WILDLIFE MANAGEMENT AND RESEARCH

D. Fraser
Ontario Ministry of Natural Resources
Wildlife Branch
Maple, Ontario

Wildlife management and research make substantial use of radio telemetry, radar, and aerial photography, and more limited use of thermal scanning and satellite imagery and data. Examples are reviewed to illustrate the use of these remote sensing techniques in wildlife studies, and reasons for both the success and failure of remote sensing when applied to wildlife are discussed.

La gestion de la faune et la recherche sur la faune font un usage substantiel de radio télémétrie, radar et photographie aérienne et un usage plus restreint de balayage thermique et d'images et données satellites. L'auteur passe en revue des exemples pour illustrer l'emploi de ces techniques de télédétection dans les études de la faune et il disserte sur les raisons des succès et faillites de la télédétection appliquée à la faune.

INTRODUCTION

When I began zoological research in a cramped laboratory in Scotland, the work consisted mainly of watching animals at close quarters in a controlled environment. When I switched from mice to moose, I found myself in an entirely different kettle of vertebrates. The first thing I received was a box of old data from a study on movement patterns of moose. Because few animals in the study had been seen by human beings more than two or three times, the animals' movements had to be determined exclusively by remote means--specifically through signals from a radio transmitter attached to the neck of each moose. Little of the study area had been seen on the ground by those conducting the study, so virtually all classification and mapping of habitat had to be done by remote means as well--in this case by black and white aerial photography. This, for me, was an appropriate introduction to the fact that if an animal is secretive, nocturnal, wide-ranging, or inaccessible, its behavior and physiology can rarely be studied except by remote means. Furthermore, for extensive wildlife management on large tracts of land, the classification and mapping of habitat almost invariably requires remote techniques.

RADIO TELEMETRY

For many types of wildlife, radio telemetry is the most important type of remote sensing. Since its introduction in the early 1960s, radio telemetry has played an increasing role in wildlife studies (Fig. 1).

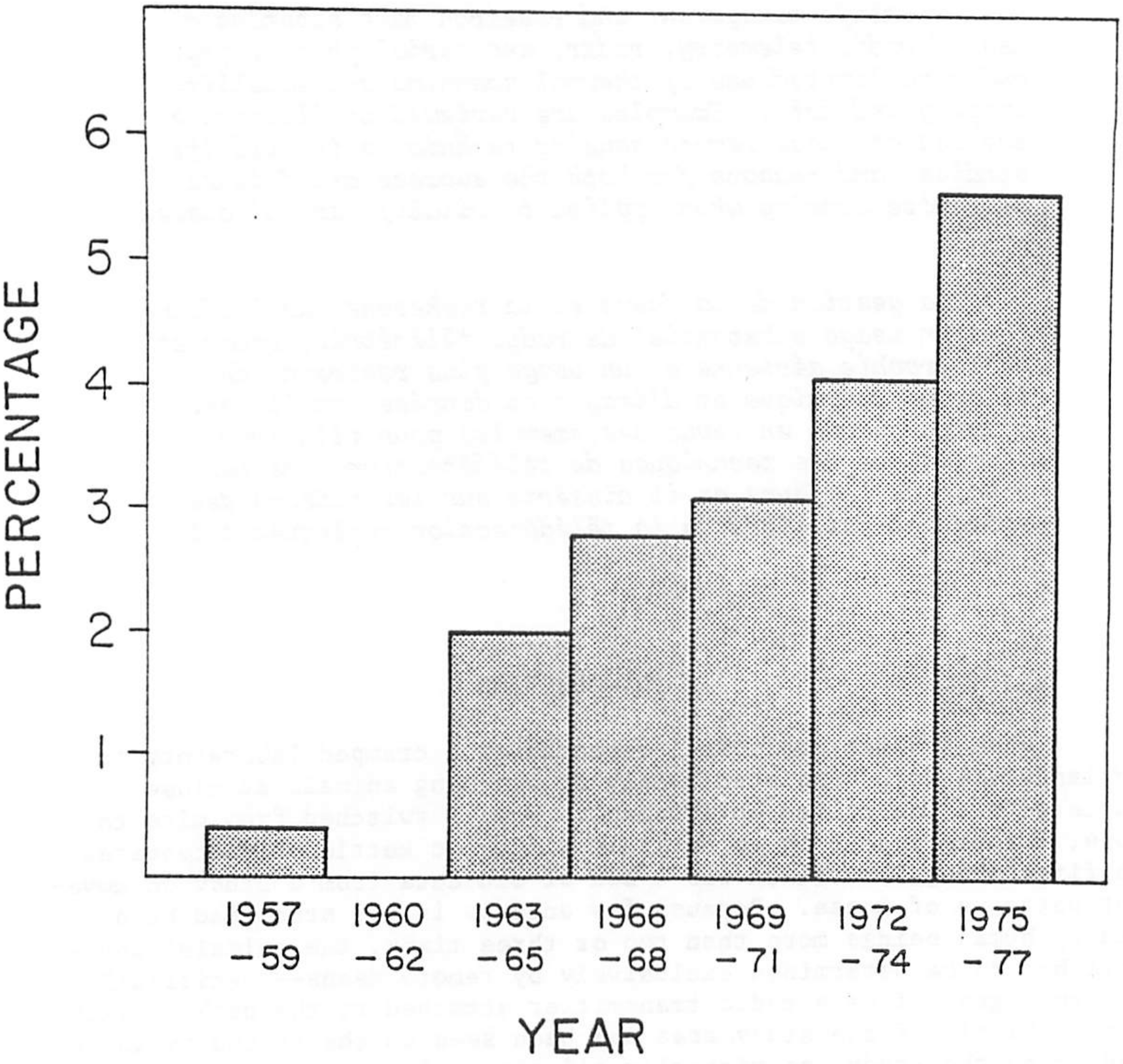


Fig. 1. Percentage of articles published in *The Journal of Wildlife Management* describing or using radio telemetry methods between 1957 and 1977.

Traditionally, radio telemetry has been used to locate animals in studies of behavior, migration, home range, dispersal and habitat selection. A typical example is a study in northwestern Ontario in which eight moose (*Alces alces*) were located at weekly intervals during most of a year. This study showed the approximate area traversed by the animals and the timing of seasonal migrations, and provided some information on habitat selection (Addison et al. 1980).

As in many earlier studies, this work involved a small number of animals located at infrequent intervals, and there was little opportunity to study social interactions or relationships with predators. Furthermore, the technology was rather cumbersome, the procedure for locating animals was labor-intensive rather than automated, and the equipment was not very reliable.

An example of more modern radio tracking comes from current research on the transmission of rabies in southern Ontario. The work involves simultaneous tracking of red foxes (*Vulpes vulpes*), skunks (*Mephitis mephitis*), raccoons (*Procyon lotor*), and coyotes (*Canis latrans*). Nearly 200 individual animals have been studied--some by intensive tracking, with locations determined every 15 to 30 minutes for several days at a time (D.R. Voigt, unpublished). The data are analyzed by complex computing equipment and specially designed programs (Voigt and Tinline 1979). The results provide many new insights into the ecology of the animals and social relationships within and between species. What is perhaps most important, the study has revealed the occasional, long-range dispersal movements by which red foxes can carry the rabies virus from an outbreak centre to a largely uninfected area.

Polar bears (*Ursus maritimus*) pose an interesting problem, as they are known to travel for hundreds of kilometres in arctic seas where radio tracking by conventional light aircraft is not feasible. To solve the problem, transmitters were developed which could be tracked by the Nimbus 6 satellite, and movements up to 1 300 km were recorded for bears travelling between Alaska and the northern USSR (Kolz et al. 1978).

Equally exciting for a wildlife biologist are the new automatic tracking systems such as the one being developed at Grimsö, Sweden. In this system a central station sends a signal which activates an animal-borne transmitter. The "reply" signal from the animal is picked up at three receiving stations, the information is relayed to a central station and the animal's location is calculated automatically by computer. The equipment is capable of tracking up to 60 animals simultaneously, and recording locations and physiological data once every two minutes.

Some of the smallest developments are as exciting as the large ones. In the past, a typical collar for black bears (*Ursus americanus*) weighed half a kilogram, was laborious to construct, unpredictable in performance, and gave information on the animal's location only. This collar has been replaced by one half as heavy and twice as reliable which provides more information on the animal. The innovation was made possible by improved batteries and components including a printed circuit board, designed by Lotimer (1979) at Maple, which cuts the time for construction of the transmitter by two thirds. With an extra capital investment, thick film technology can be used to produce packages one quarter to one tenth the size for use on birds and small mammals.

The use of radio telemetry has extended to other areas of wildlife research in recent years. Radio equipment is now being used to transmit data on the heart rate, body temperature, electrocardiogram, and stomach pH of free-ranging animals for studies of bio-energetics and physiology (e.g., Moen 1978). Alaskan workers have gathered some tradition-shattering information on the causes of moose calf mortality by equipping animals with radios which notify biologists when a calf has died (Franzmann and Peterson 1978). The signals from Lotimer's (1979) printed circuit board transmitter also tell whether an animal is active or resting, and this type of behavioral information could be expanded substantially.

There are many potential uses of the technology for routine management purposes as well, although cost and imagination impose certain limitations. In California, where neither cost nor imagination ever seem to be much of a problem, the commercial use of radio tracking is almost ancient history. Once research showed that radio-equipped dolphins (*Stenella* sp.) could be used to locate beds of tuna (*Thunnus* sp.), commercial tuna fishermen began to buy and use highly specialized radio-tracking equipment to lead them to promising fishing areas. The practice was widespread until it became illegal some years ago (B. Byrnes, pers. comm.).

RADAR

Radar is an important remote sensing tool in wildlife studies, particularly for work on migratory birds, bats, and insects (Richardson 1978). Interest in this use of radar began during the Second World War, when radar operators sometimes had difficulty distinguishing small aircraft from flocks of birds. Since then, radar has been used in the scientific study of bird migration in various parts of the world.

In 1969 a collision between a civil aircraft and a flock of snow geese near Winnipeg provided the stimulus for research by the Canadian Wildlife Service to determine ways of predicting the hazard to aircraft from migrating birds (Blokpoel 1974). Initial work with radar led to the development of a weather-based system for this purpose (Blokpoel 1973). Current work involves prototype radar systems designed for use at airports to give immediate information on the bird hazard in the landing and take-off area (Hunt 1975, 1977).

THERMAL SCANNING

Thermal scanning showed early promise for the census of large animals from the air. Ideally the scanner will detect radiant energy from a warm animal against a cooler background, but there are many complicating factors.

Thermal scanning was originally developed as classified technology for military purposes, and as recently as 1968 a publication on a thermal census of white-tailed deer (*Odocoileus virginianus*) included only an artist's impression of the imagery (Croon et al. 1968). Since then restrictions have been greatly relaxed on certain equipment, and a number of tests have been carried out. These indicate that thermal scanning shows its greatest potential for census of large animals on relatively flat terrain where there is little interference from a leafy canopy overhead. Even on such terrain, however, climate and vegetation create many complications. Two recent reviews concluded that thermal scanning has only limited potential for wildlife census (Lavigne et al. 1977, Heyland 1978). This view is perhaps a trifle too gloomy. If we could only convince the military that the country is riddled with enemy agents cunningly disguised as moose and caribou, we might suddenly find that there are effective tools for their detection.

AERIAL PHOTOGRAPHY

In wildlife studies, aerial photography remains the great workhorse for remote sensing of the environment. In a recent survey of uses of remote sensing for wildlife (Cihlar and Rubec 1979), all but 10 of the 69 projects used aerial photography. Furthermore, many uses of aerial photography were described as operational rather than research, whereas many of the uses of satellite data were still in the research stage. Aerial photography has been used to study a host of wildlife species in forest, alpine, wetland and open habitats. Because the techniques are so familiar, I will not dwell on them.

In Ontario the major synthesis of aerial photograph information is the Forest Resource Inventory (FRI) mapping program. Unfortunately, the FRI concentrates on merchantable timber and, as a result, it is not as useful for wildlife management as it could be with some modification. Wildlife biologists generally want to know the height and species composition of deciduous understory, types of wetlands, and the nature of ground cover and regeneration in logged or burned areas. I once attended a somewhat emotion-charged meeting at which it was proposed that FRI maps be used to create habitat maps for moose. The idea was resoundingly rejected by wildlife field staff, who felt that the FRI simply didn't contain the relevant information.

The FRI, an important provincial program, represents the only systematic attempt to map vegetation in remote areas; hence, it is disappointing that it is not of more value in wildlife management. Perhaps new developments in remote sensing will allow the FRI to become a more complete inventory of the resources of forested areas, instead of a shopping catalogue of merchantable trees.

In addition to its uses in habitat work, aerial photography has a variety of specialized uses in wildlife studies. Vertical aerial photography has been used in the census of nesting pairs of Lesser Snow geese (*Anser caerulescens caerulescens*) in the Canadian arctic (Kerbes 1975). The reproductive success of geese can be estimated from the ratio of adults to juveniles as determined from oblique aerial photography of birds on the ground or in the air (Hanson et al. 1972). Aerial photography can be used to study the abundance of young in herds of caribou (*Rangifer tarandus*), bison (*Bison bison*), and other mammals which live in relatively open habitat (e.g., Parker 1972, Sinclair 1969, B. Stephenson, pers. comm.). Other applications include census of beaver colonies (*Castor canadensis*) and of nesting gulls (*Larus* sp.) (M. Novak, pers. comm., Blokpoel 1977). A particularly appropriate application of aerial photography is evident in the census of Harp Seal pups (*Phoca groenlandica*) developed by Lavigne and his co-workers. With their white coats against a white background of ice and snow, Harp Seal pups cannot be counted accurately from a conventional aerial photograph census. However, Lavigne and Øritsland (1974) found that the white coat absorbs a large amount of ultraviolet radiation. With ultraviolet photography, the pups can be counted, and an accurate population estimate is possible (Lavigne 1976).

SATELLITE IMAGERY AND DATA

The land-scanning satellites provide a newer form of remote sensing which so far has seen relatively limited application to wildlife studies, although much research is now being devoted to the subject. Applications of LANDSAT information to wildlife work can be divided into two broad categories.

The first category consists of simple discriminations based on satellite data, usually over large areas where aerial photography or other means of gathering more refined information are not feasible. An excellent example is the annual monitoring of snow cover clearance from Arctic goose nesting areas. The productivity of several species of geese is closely related to the date of snow clearance from the nesting areas. Satellite data can be used to detect unusually early or late disappearance of snow cover, and therefore to predict high or low production (Reeves 1978). Other successful uses include simple vegetation typing over vast areas of grey kangaroo (*Macropus giganteus*) habitat in Australia (Hill and Falconer 1978), and identification of shallow Arctic lakes which are potential breeding areas for Ross' geese (*Anser rossii*) (Kerbes 1978).

The second category consists of more detailed vegetation mapping in smaller areas, usually as a cheaper alternative to aerial photography. For this type of work, LANDSAT information has been less successful because of its limited resolution and inability to make certain important discriminations.

The poor resolution proved to be a problem in evaluating waterfowl habitat in the prairie pothole region (Gilmer et al. 1978). Many ponds important to waterfowl were too small to be detected by LANDSAT sensors, and the data had to be revised by means of correction factors derived from observations made from aircraft.

The inability to make important discriminations on the basis of spectral signature alone is mentioned repeatedly in wildlife studies in which LANDSAT data are used. In an Alaskan study, alpine barrens and mountain shadow were confused with shallow water (LaPerriere and Morrow 1978). When attempts were made to estimate food available to Lesser Snow geese taking refuge in winter, it was not possible to distinguish soybean crops from corn (Klaas et al. 1978). In a broad, regional vegetation mapping program in Texas, heavily grazed grassland could not be distinguished from urban areas nor marshes from flooded rice fields (Frye et al. 1978). In all these cases the satellite data were still considered valuable, but other sources of information had to be used to make the discriminations which could not be made from the spectral signatures. In one published study the problems with the LANDSAT interpretation were so great that aerial photography and other sources of information were used instead (Baumann et al. 1978).

Recently a number of wildlife biologists have urged a much greater use of LANDSAT data (Reeves et al. 1975, Lavigne et al. 1977, Heyland 1978), and in general this is good advice. With current technology, however, resolution capacity remains a problem, and spectral signature alone is not capable of making a number of discriminations important in wildlife habitat work. Any use of LANDSAT, particularly for habitat mapping, will have to include careful study to determine which discriminations cannot be made by this means.

CONCLUDING REMARKS

In future work on wildlife, we can expect to see continued and diversified use of radio telemetry, perhaps combined with other types of remote sensing so that an animal's movements and physiology can be interpreted in relation to habitat. We can expect continued use of aerial photography, perhaps with greater emphasis on color infrared techniques (Carneggie and Marmelstein 1978). We can expect continued use of radar and satellite data for certain purposes, and a good deal of research to identify the strengths and weaknesses of LANDSAT data as a means of habitat mapping.

Two things stand in the way of increased use of remote sensing for wildlife. The first is a lack of adequate resources. The Ontario government's wildlife research effort is not small by Canadian standards, but we could not contemplate purchasing the equipment for automatic radio tracking as is done in Sweden and France, even though this capital investment would provide a much more cost-effective system than our present labor-intensive methods. Much the same is true of tracking animals by satellite telemetry. Furthermore, it is doubtful whether our wildlife managers could afford to use thermal scanning for routine wildlife census even if the technical problems were solved.

The second obstacle is the limited understanding between biologists and remote sensing specialists. In the early stages of wildlife radio tracking, communication between the biologists and the radio engineers was poor. Galler (1965) describes a preliminary meeting between the two groups. The biologists, ignorant of radio technology, described a hopelessly elaborate set of requirements for a tracking system. The engineers, equally ignorant of the biological realities, designed a system which would need a wooly mammoth or brontosaurus to carry it, and a military budget to pay the bills.

But that stage is now long past in wildlife telemetry. Many wildlife research workers, though leaving the gadgeteering to the engineers, have a good grasp of radio technology, and the engineers show an impressive understanding of the biological uses of their handiwork. The biologist and engineer often work in the same laboratory or department, as is the case in our own ministry's Wildlife Research Section which includes a radio engineer as one of the 11 permanent positions.

In the case of the newer types of remote sensing, I think wildlife biologists are going through a similar development process, but we are still at the stage of the wooly mammoth and brontosaurus. The real progress will not be made until the biologist and remote sensing specialist achieve a far greater degree of communication and understanding of each other's art.

ACKNOWLEDGMENTS

I am very grateful to H. Blokpoel, B. Byrnes, P. Croskery, C. Douglas, J. Hall, H. Hristienko, F.R. Hunt, A.L. Kolz, D.M. Lavigne, J. Lotimer, H.G. Lumsden, C.D. MacInnes, M. Novak, S. Pala, B. Stephenson, D.R. Voigt, O. Williams, and V. Zsilinsky for supplying ideas, advice and material for this presentation. This paper is Contribution No. 79-22, Wildlife Research Section, Ontario Ministry of Natural Resources.

LITERATURE CITED

Addison, R.B., Williamson, J.C., Saunders, B.P., and Fraser, D. 1980. Radio-tracking moose in the boreal forest of northwestern Ontario. Can. Field-Nat. 94 (in press).

Baumann, R.H., Johnston, J.B., and Gosselink, J.G. 1978. Habitat mapping and inventory in the Chenier Plain of Louisiana and Texas. p. 44-49 *in* Pecora IV: Proceedings of the Symposium. Nat. Wildl. Fed., Sci. Tech. Ser. No. 3.

Blokpoel, H. 1973. Bird migration forecasts for military air operations. Dep. Environ., Can. Wildl. Serv., Ottawa, Ont. Occas. Pap. No. 16. 18 p.

Blokpoel, H. 1974. Migration of Lesser Snow and Blue Geese in spring across southern Manitoba. Part 1: Distribution, chronology, directions, numbers, heights and speeds. Dep. Environ., Can. Wildl. Serv., Ottawa, Ont. Rep. Ser. No. 28. 30 p.

Blokpoel, H. 1977. Gulls and terns nesting in northern Lake Ontario and the upper St. Lawrence River. Dep. Environ., Can. Wildl. Serv., Ottawa, Ont. Progr. Note No. 75. 12 p.

Carneggie, D.M. and Marmelstein, A. 1978. A perspective on remote sensing for wildlife management. p. 392-397 *in* Pecora IV: Proceedings of the Symposium. Natl. Wildl. Fed., Sci. Tech. Ser. No. 3.

Cihlar, J. and Rubec, C. 1979. User survey of applications of remote sensing in Canada for wildlife, forestry, wildlands and biophysical inventory. Can. Advis. Comm. on Remote Sensing, Ottawa, Ont. 49 p.

Croon, G.W., McCullough, D.R., Olson, C.E., and Queal, L.M. 1968. Infrared scanning techniques for big game censusing. J. Wildl. Manage. 32:751-759.

Franzman, A.W., and Peterson, R.O. 1978. Moose calf mortality assessment. Trans. North Am. Moose Conf. Workshop 14:247-269.

Frye, R.G., Brown, K., Frentress, C.D., McCarty, D.M., McMahan, C.A., and Anderson, S. 1978. Production of vegetation type-maps from LANDSAT digital data. p. 57-64 *in* Pecora IV: Proceedings of the Symposium. Natl. Wildl. Fed., Sci. Tech. Ser. No. 3.

Galler, S.R. 1965. Perspectives in animal telemetry. p. 237-254 *in* C.A. Caceres, *Ed.* Biomedical Telemetry. Acad. Press, New York.

Gilmer, D.S., Colwell, J.E., and Work, E.A. 1978. Use of LANDSAT for evaluation of waterfowl habitat in the prairie pothole region. p. 197-203 *in* Pecora IV: Proceedings of the Symposium. Natl. Wildl. Fed., Sci. Tech. Ser. No. 3.

Hanson, H.C., Lumsden, H.G., Lynch, J.J., and Norton, H.W. 1972. Population characteristics of three mainland colonies of Blue and Lesser Snow Geese nesting in the southern Hudson Bay region. Ont. Min. Nat. Resour., Res. Rep. (Wildlife) No. 92. 38 p.

Heyland, J.D. 1978. Imaging remote sensing systems for animal censuses. p. 162-170 *in* Pecora IV: Proceedings of the Symposium. Natl. Wildl. Fed., Sci. Tech. Ser. No. 3.

Hill, G.J.E., and Falconer, A. 1978. Relevance of LANDSAT to kangaroo management in Queensland, Australia. p. 287-293 *in* Pecora IV: Proceedings of the Symposium. Natl. Wildl. Fed., Sci. Tech. Ser. No. 3.

Hunt, F.R. 1975. Automatic radar equipment to determine bird strike probability. Part I. Night-time passerine migration. Natl. Res. Counc. Can., Field Note No. 69. 24 p.

Hunt, F.R. 1977. Automatic radar equipped to determine bird strike probability. Part II. Migrating water-fowl flocks. Natl. Res. Counc. Can., Field Note No. 75. 18 p.

Kerbes, R.H. 1975. The nesting population of Lesser Snow Geese in the eastern Canadian Arctic: A photographic inventory of June 1973. Dep. Environ., Can. Wildl. Serv., Ottawa, Ont. Rep. Ser. No. 35. 47 p.

Kerbes, R.H. 1978. Identification of Ross' goose colonies from LANDSAT imagery. p. 212-213 *in* Pecora IV: Proceedings of the Symposium. Natl. Wildl. Fed., Sci. Tech. Ser. No. 3.

Klaas, E.E., Anderson, W.H., and Frederick, R.B. 1978. Use of LANDSAT imagery for estimating food available to refuging Lesser Snow geese. p. 89-94 *in* Pecora IV: Proceedings of the Symposium. Natl. Wildl. Fed., Sci. Tech. Ser. No. 3.

Kolz, A.L., Lentfer, J.W., and Fallek, H.G. 1978. Polar bear tracking via satellite. p. 137-144 *in* Proc. Annu. Rocky Mount. Bioeng. Symp. 15.

LaPerriere, A.J., and Morrow, J.W. 1978. Use of LANDSAT data for the wetland inventory of Alaska. p. 95-99 *in* Pecora IV: Proceedings of the Symposium. Natl. Wildl. Fed., Sci. Tech. Ser. No. 3.

Lavigne, D.M. 1976. Counting Harp Seals with ultra-violet photography. Polar Rec. 18:269-277.

Lavigne, D.M., and Øritsland, N.A. 1974. Ultraviolet photography: a new application for remote sensing of mammals. Can. J. Zool. 52:939-941.

Lavigne, D.M., Øritsland, N.A., and Falconer, A. 1977. Remote sensing and ecosystem management. Norsk Polarinstitutt, Skrifter No. 166. 51 p.

Lotimer, J. 1979. A versatile coded wildlife transmitter. p. 185-191 *in* C.J. Amlaner and D.W. Macdonald, *Ed.* A Handbook on Biotelemetry and Radio Tracking. Pergamon Press, Oxford. xix + 804 p.

Moen, A.N. 1978. Seasonal changes in heart rates, activity, metabolism, and forage intake of white-tailed deer. J. Wildl. Manage. 42: 715-738.

Parker, G.R. 1972. Biology of the Kaminuriak population of barren-ground caribou. Part 1. Total numbers, mortality, recruitment, and seasonal distribution. Dep. Environ., Can. Wildl. Serv., Ottawa, Ont. Rep. Ser. No. 20. 95 p.

Reeves, H.M. 1978. Applications of satellite imagery to management of Arctic nesting geese. p. 219-226 *in* Pecora IV: Proceedings of the Symposium. Natl. Wildl. Fed., Sci. Tech. Ser. No. 3.

Reeves, H.M., Munro, R.E., and Marmelstein, A.D. 1975. USFW activities in application of satellite imagery to good management. Proceedings of a Workshop on Remote Sensing of Wildlife, Quebec, Que., 18-20 Nov., 1975. Min. du Tourisme, de la Chasse et de la Pêche, Québec, Qué.

Richardson, W.J. 1978. Radar techniques for wildlife studies. p. 171-179 *in* Pecora IV: Proceedings of the Symposium. Natl. Wildl. Fed., Sci. Tech. Ser. No. 3.

Sinclair, A.R.E. 1969. Serial photographic methods for population, age and sex structure. p. 87-93 *in* W.G. Swank, R.M. Watson, G.H. Freeman, and T. Jones, *Ed.* Proceedings of the Workshop on the Use of Light Aircraft in Wildlife Management in East Africa. East Afr. Agric. For. J. 24 (special issue).

Voigt, D.R., and Tinline, R.R. 1979. Strategies for analyzing telemetry movement data. p. 387-404 *in* C.J. Amlaner and D.W. Macdonald, *Ed.* A Handbook on Biotelemetry and Radio Tracking. Pergamon Press, Oxford. xix + 804 p.

Discussion

In view of the fact that he had questioned the usefulness of FRI photography and inventory for wildlife management, the speaker was asked to explain how he thought their usefulness could be increased. Imagery that would permit the identification of deciduous brush on cutover areas, wetland sites important to wildlife, and shrub and ground vegetation under a forest canopy was cited as being necessary for wildlife management. Some promise was seen in the use of supplementary aerial photography to satisfy this need.

A PRELIMINARY ASSESSMENT OF THE VALUE OF SATELLITE REMOTE SENSING FOR THE ONTARIO MINISTRY OF NATURAL RESOURCES DISTRICT LAND USE PLANNING PROGRAM

M.S. Millar
Supervisor of Land Use Planning
Land Use Coordination Branch
Ontario Ministry of Natural Resources
Toronto, Ontario

With certain exceptions, "LANDSAT" imagery appears to add little information to that already available from traditional information sources, for use in the Ministry's district land use planning program. However, use of LANDSAT imagery for this level of land use planning has not been thoroughly evaluated.

À quelques exceptions près, les images "LANDSAT" semblent ajouter peu de données à celles déjà disponibles grâce aux sources d'information classiques, pour le programme de planification de l'utilisation des terres par district en cours au Ministère. Cependant, l'emploi d'images LANDSAT à ce niveau de planification de l'utilisation des terres n'a pas été évalué à fond.

INTRODUCTION

I would like to begin my presentation by stating my conclusion: with a few exceptions, the use of satellite remote sensing imagery appears to add little information to that already available from traditional sources, for use in the Ontario Ministry of Natural Resources district land use planning program.

Before I am asked to leave the room or instructed never again to darken the doors of the Ontario Centre for Remote Sensing (OCRS), I would like to explain the criteria I used to arrive at this conclusion.

First, I am talking only about remote sensing from satellites and only about images and tapes available from LANDSAT. I have not considered remote sensing from aircraft in this discussion because there is no question of the value of air photography, when applied to specific areas or problems, for resource management or other uses. However, its application on a province-wide basis is impractical.

Second, I am concerned only with the output available from the digital analysis system now in use at OCRS since it is the equipment on which OCRS staff intend to concentrate their efforts.

Third, I did not seek the assistance of the Canada Centre for Remote Sensing or similar agencies in the United States since I felt it was most convenient to deal with the OCRS. However, I discussed the matter with a consultant who has done planning projects for the ministries of Natural Resources, Industry and Tourism, and Transportation and Communications, and he generally verified my conclusion.

Fourth, I restricted myself to the application of LANDSAT imagery to a specific kind and level of land use planning. I acknowledge its value in provincial, national and world planning. At the district level we are trying to determine *where* the various Ministry programs can best be carried out. This type of land use planning is generally not as detailed as that done for most official planning areas. It should not be confused, either, with resource management planning, which is concerned with *how* targets are reached on the land allocated by land use planning, and requires a more detailed analysis of physical and biological features.

The Ministry of Natural Resources develops provincial policies consisting of objectives and targets for each program activity carried out in the field. The province has been divided into three planning regions for the purpose of preparing three strategic land use plans. In these plans the provincial policies have been modified to meet regional conditions and targets have been tested at a gross level to see if they can be met on the existing land and water base. The planning region targets are eventually broken down and assigned to each of the Ministry's 48 administrative districts. The district then adjusts the regional policies to meet local conditions and the assigned targets are tested at a finer level of detail to see if they can be met. The district land use plan will identify how the Ministry intends to use Crown land and water and how it wishes to influence the use of private land to achieve its own and other government objectives as expressed through the assigned targets. At this level of land use planning data are normally collected on 1:50 000 scale National Topographic Series maps and the final plan is prepared at a scale of 1:250 000.

Prior to preparing this paper I was limited in my experience with satellite remote sensing to an awareness of its use for weather forecasting and for identifying and mapping forest cutovers, burns and the location of roads. I also attended a five-day course, given by OCRS, in which participants were made aware of the potential uses of both satellite and supplemental air photography (SAP).

On the basis of this limited experience, I decided to test the usefulness of LANDSAT imagery at the district level of land use planning. For the preparation of district land use plans the Ministry provides a list of data to be collected and analyzed. There are five categories: a) people, b) natural resources, c) present use, developments, trends and projections, d) other plans, and e) problems and issues.

Analysis of the LANDSAT imagery was considered applicable to only the first three categories. The individual items in each of these categories are listed in Table 1. I will review each category and state whether LANDSAT imagery can provide or supplement information not readily available from traditional sources, such as natural resource maps in the Canada and Ontario Land Inventory series.

Table 1. Information requirements for Ontario Ministry of Natural Resources district land use plans

---

a) people

- Brief history of settlement and development
- Population - number, distribution and projections

b) natural resources

- Land and water area
- Climate and air quality
- Watersheds and water quality
- Bedrock and surficial geology
- Topography and soil depth
- Agriculture capability
- Timber capability
- Mineral potential including aggregate and fuels
- Recreation capability
- Historic and cultural areas and sites
- Forest cover
- Fish productivity and populations
- Wildlife capability, suitability and populations
- Wetland

c) present uses, developments, trends and projections

- Land tenure
- Urban commercial, industrial and secondary industries that are particularly related to resources
- Rural residential
- Transportation and communications (roads, railways, airports, harbors, power lines, pipelines)
- Agriculture
- Timber operations and the forest industry
- Mining and the mining industry
- Trapping
- Commercial fishing
- Wild rice
- Public recreation areas

a) People

Brief history of settlement and development: The available imagery does not go back far enough in time to establish any pattern or trend except in rapidly expanding areas such as the Golden Horseshoe. Certain development and settlement trends may be evident if we note recent physical changes such as forest cutovers, old logging roads and clearings that accommodated earlier communities, and associated land clearing activities such as agriculture and forestry.

b) Natural resources

Land and water areas: At present the only way information can be obtained with any degree of accuracy is through manual collection in each of the 48 districts. This information is vital for our target testing procedure. Through the use of a digital analysis computer the land and water areas can be determined for each district once a computer program has been written to identify the district boundaries. This program has now been written for a test area. If it is necessary to separate out wetlands at this stage the land use planners and resource managers must provide the criteria to be used and OCRS will test the program's practicability.

Climate and air quality: For most areas adequate meteorological and air quality records are available. For specific air pollution problems LANDSAT imagery can be used only to identify the extent of *severe* damage at locations such as Sudbury and Wawa. Both SAP and ground checks are required to map the extent of changes resulting from most forms of air pollution.

Watersheds and water quality: This information is necessary for assessing various resource potentials and uses, delineating area boundaries and identifying the location of potential downstream impacts that could result from proposed land or water use activities in a particular area. Watershed boundaries and direction of flow are best determined from NTS maps. However, the percentage of forest cover, open areas, built-up areas, water bodies and agricultural lands could be determined for a given watershed using LANDSAT imagery. The determination of various levels of water quality requires finer detail than can be provided by satellite imagery. Water observed as off-color, because of sediments in suspension or growth of vegetation, could still be of a satisfactory quality. Large concentrations of algae on larger bodies of water can often be detected once the algae begin to die. Digital analysis may be able to detect such concentrations of algae on smaller bodies of water.

Bedrock and surficial geology: Information of this nature can be obtained from a variety of sources such as the Ontario Geological Survey maps and reports and "The Physiography of Southern Ontario" by Chapman and Putnam. A future source will be the Northern and Southern Ontario Engineering Geology Terrain Studies now under way. The use of LANDSAT imagery in combination with existing geological maps may reveal patterns not previously apparent. For example, the extent of large faults can be mapped more accurately. For much of northern Ontario and the Hudson Bay Lowlands no surficial geology maps are available. However, using the LANDSAT imagery supplemented by existing aerial photography and some field checking, OCRS has prepared preliminary maps which identify the extent of major surficial deposits. These maps are to be published over the next two years and will be useful in the preparation of the land use plans for this area.

Topography and soil depth: Information regarding topography and depth of soil is very important for land use planning purposes. In addition to the sources mentioned in the previous section, this type of information can be obtained from existing National Topographic Series, agricultural soil and Ontario Land Inventory Land Classification maps. Unfortunately, only large bare rock areas and extensive glacial deposits can be identified from satellite imagery.

Agricultural capability: For our purposes this information can be obtained from CLI Soil Capability for Agriculture maps and the local agricultural representatives.

Timber capability: A gross estimate of timber capability for parts of the province not covered by the OLI, CLI or Ministry Forest Resources Inventory mapping could be made using LANDSAT imagery supplemented by ground checks. This has been done in the northern part of the province and may be adequate for district land use planning in the areas concerned.

Mineral potential including aggregate and fuels: Sources of this information are the Ontario Geological Survey maps and reports supplemented by the knowledge of local Ministry resident geologists. At present, mineral, oil and gas potential cannot be detected from satellite imagery. As mentioned previously, preliminary surficial geology maps have been prepared for the northern part of the province and areas of potential aggregate have been identified. For the balance of the province the available aggregate information cannot be improved upon by the use of LANDSAT imagery. With regard to the use of peat as a fuel, it has been established that Canada has the second largest peat resource in the world next to Russia. OCRS has a mapping project under way in the Hudson Bay Lowlands using satellite imagery to determine this potential.

Recreation capability: There are many reports that provide some of this information for particular areas or activities. The CLI and OLI Land Capability for Recreation maps should be used to obtain a generalized perspective of the district's potential. Satellite imagery is of no assistance here except where it is used in conjunction with other aerial photography and field checking to locate large scale provincial or federal parks such as Polar Bear Provincial Park.

Historical and cultural areas and sites: Only lower level photography is of use for collecting this type of information.

Forest cover: Forest cover information can be useful for identifying forestry, wildlife and certain types of recreation potential, as well as for monitoring the progress of a variety of activities such as logging, agricultural clearing and road construction. The Forest Resources Inventory (FRI) and the National Topographic Series maps are normally used to obtain forest cover but both are dated. The use of satellite imagery seems to hold considerable promise for supplying this type of information. Depending on the breakdown required by the land use planner or resource manager, maps can be prepared and areas calculated for forested land (hardwood, conifer, mixedwood, cutovers, burns), wetlands (bogs, open bogs, treed bogs, fens, marshes) and nonforested land (agricultural areas, urban areas, roads, transmission lines, etc.).

Depending on the purpose and on the level of detail required, forest cover can be ascertained much faster and at a more acceptable degree of accuracy from satellite imagery than from attempts to generalize the FRI. There is a problem of separating nonforested land uses in many areas of southern Ontario because where such features as transmission lines and roads cross agricultural areas, they often appear just as cleared land.

Fish productivity: One of the parameters of fish productivity is the depth of the water body but depths of water cannot be determined with any degree of accuracy from satellite imagery. A color variation in different water bodies may indicate a shallow lake or the presence of sediments in suspension, as in Wabigoon Lake in the Dryden District. A new satellite about to be launched may provide thermal imagery and it may therefore be possible to distinguish cold and warm water bodies.

Wildlife capability and suitability: One source of such information is the CLI and OLI Land Capability for Wildlife and Waterfowl maps. However, this is another area in which satellite imagery shows some promise. The patterns of forest cover and wetlands, such as marshes and fens, can be mapped and analyzed and the capability and suitability for various wildlife species can be determined. However, aside from identifying cutover and burned areas and estimating their age at 10-year intervals up to age 20, we cannot ascertain the age and condition of forest stands with any degree of accuracy from satellite imagery. OCRS has identified habitat for Woodland Caribou in the Hudson Bay Lowlands from LANDSAT imagery. To date the satellite imagery has proved to be of no value in estimating the capacity of the habitat to sustain fur-bearing animals that are trapped for their furs. It is even difficult to identify beaver ponds with SAP.

Wetlands: The preservation of key wetlands is becoming increasingly important. OCRS feels they are now able to distinguish bogs, open bogs, treed bogs, fens and marshes from LANDSAT imagery. Depending on the degree of accuracy required this may prove useful in identifying the potential of such wetlands for various species of waterfowl.

- - - o - - -

In summary, for determining the natural resource potential of satellite imagery for district planning, LANDSAT seems to offer the most promise in calculating land and water areas, identifying the extent of significant concentrations of certain types of algae on large bodies of water, providing a gross estimate of timber capability in previously uninventoried areas of the far north, estimating peat potential, and identifying patterns of forest cover and wetlands to an acceptable level of accuracy.

c) Present uses, developments, trends and projections

The analysis of present use and developments is an important part of the Ministry's land use planning process. Generally it is wisest to disrupt present use as little as possible. Awareness of physical developments such as cottages and roads is an important factor in determining the use an area receives and in deciding whether it is capable of accommodating other forms of use. A dense cottage area is generally considered unsuitable for a potential wilderness park or for hunting, as future conflicts could be expected between hunters and cottagers. The continuing spread of forms of development such as cottages and roads needs to be monitored and inventoried constantly, but this is a difficult task. One method of determining recreational use in an area is to count the number of cars in parking lots or boats out fishing.

It was hoped that analysis of satellite imagery would assist in this work. The boundaries of urban development cannot be determined with any degree of accuracy except around the larger population centres. The Ministry is most interested in development that takes place outside municipal boundaries. At present cottages cannot be distinguished from bare bedrock. With regard to linear features such as trails and resource roads, the smallest that can be identified with any degree of accuracy are secondary logging roads. Small concentrations of cars or boats cannot be identified. As mentioned previously, the location of features such as roads, transmission lines and pipelines is difficult to ascertain where they are associated with cleared land. Unfortunately, many of these land uses do not account for space in proportion to their significance and thus cannot be detected with satellite imagery. Often SAP is required during particular seasons to provide the necessary level of detail.

Some experiments are being carried out by OCRS in cooperation with the Ministry of Agriculture and Food on crop identification from satellite imagery. The small size of fields in Ontario has proven to be a problem. One area in which they are experiencing difficulty at the present time is in distinguishing between pasture areas and hay fields. Future satellites promise higher degrees of resolution and perhaps such features as linear concentrations of cottages around the shores of lakes will be identifiable. Meanwhile, the use of satellite imagery in determining present use at the district level of land use planning seems to be confined to mapping large vegetative disturbances resulting from logging, forest fires, agricultural clearing, road construction, aggregate removal and mining operations accompanied by large tailing areas. Mapping of such areas can generally be done with an acceptable degree of accuracy.

In summary, it appears that the greatest benefit from the analysis of LANDSAT II imagery in the preparation of district land use plans is in the areas of calculating land and water areas, providing surficial geology maps where none existed before, mapping patterns of forest cover and wetlands to assist in assessing the capability of areas for timber, wildlife and waterfowl production and certain types of outdoor recreation activities and mapping present uses and disturbances mentioned above.

However, there is another problem that should not be overlooked. To obtain the LANDSAT tapes for determining the land and water areas in the 48 Ministry administrative districts would cost $33,000 because 150 tapes, each costing $220, are required. Unfortunately, this material cost often cannot be spread over many of the other data items since tapes made during different seasons are required to identify certain features. Others can probably use the same tapes so our contribution could be considered an investment in the advance of LANDSAT use.

Therefore, in certain instances the expense may not be justified when information that is sufficiently accurate and detailed can be obtained from more conventional sources. On the other hand, we should make full use of all the photos and tapes available at various resource centres. We must remember, too, that OCRS is research oriented rather than operational. It may develop interpretive techniques that will increase the usefulness of satellite imagery but it cannot carry out projects for other agencies. When we tender to have work done outside government we may find that a company does not have the necessary equipment and/or interpretive expertise and the cost may be much higher than we can afford.

Were our expectations too great? Perhaps land use planners have been led to expect that satellite imagery will provide them with certain types of information or a level of accuracy that it is not capable of supplying at the present time. While there is talk of future satellites providing greater degrees of resolution, perhaps satellite imagery is most practical for biophysical classifications at a regional level, for monitoring land use activities such as logging, and for mapping disturbances such as forest fires, floods and blowdown. Or perhaps we are too impatient and the required interpretive techniques have not yet been developed.

Before "throwing out the baby with the bath water", I think we had better pause and re-evaluate the situation. I am tempted to compare the doubts I have raised about the usefulness of LANDSAT imagery for district land use planning with the doubts often expressed about the Canada and Ontario Land Inventories. I know there are many conflicting opinions about the reliability and usefulness of the CLI and OLI resource capability mapping. I feel part of the disillusionment is due to the fact that users do not fully understand the basis of the inventories, or they attempt to use LANDSAT imagery in ways it was never intended to be used. It was designed for regional analysis of specific natural resource capabilities, yet many people dismiss it entirely because they know that in a particular stand of trees, the land is not Class 4 forest capability as shown on the map, but Class 1. Or, they know that there are a few sites in a specific OLI shoreland unit ranked Class 4 (i.e., for group camping and lodging) that are first-class cottage lots. Many resource people expect LANDSAT to provide infallible answers; they want to use it for estimating specific resource capabilities instead of as a source of information along with common sense and other methods. Inventories are only as good as those who prepare them, and I am sure most of you can appreciate the problems of maintaining quality control in an inventory that is being carried out in an area the size of Ontario.

I am afraid that many people may take a similar attitude to the use of satellite imagery in district land use planning and may dismiss it before it has been adequately evaluated. Land use planners and resource specialists should urge those working with satellite imagery to investigate its application to their field more thoroughly. It is my understanding that a committee has been set up in OCRS to take an in-depth look at the application of satellite imagery to Ministry land use planning. By the same token, I do not think we should accept as gospel whatever they tell us. Both land use planners and resource specialists--especially the resource specialists--should work with photos, tapes and interpretation equipment so as to understand their capabilities and determine their practical applications. Resource specialists in particular are qualified and would be able to interpret and assess the information.

I implore those who work with satellite imagery to remove it from the "magic box" category. Be frank with the user about its capabilities, make sure the user knows how to interpret the available material, and do not focus your attention exclusively on newer satellites until the usefulness of our present technology has been exhausted.

Do not dismiss the use of LANDSAT imagery in district land use planning until its potential has been thoroughly evaluated. Once the necessary techniques have been perfected and it has become a recognized land use planning tool, the costs should decrease.

Remember that satellite imagery can seldom stand alone as an information source. In combination with existing data, newly obtained imagery may often provide a reliable survey at a reasonable price. It can also be used to supplement or check existing information. One of the most important features of this technology is that it provides land use planners with a holistic view of their planning areas. Remember, too, that the implementation of a land use plan can be monitored by using satellite imagery to follow certain physical and cultural developments in the planning area that occur as a result of the plan.

Discussion

In response to the criticism that the resolution of LANDSAT imagery was inadequate for providing any information beyond that already provided by conventional aerial photography, the point was raised that the primary benefit of LANDSAT imagery is that it provides a synoptic view of larger areas. (The area coverage of one frame is 41 440 km^2.) A further advantage cited was that LANDSAT provides the opportunity to see the same view repeatedly over a short period of time, and to monitor short-term change.

WHY REMOTE SENSING FOR RESOURCE MANAGERS?

L. Sayn-Wittgenstein
Dendron Resource Surveys
Ottawa, Ontario

The role of remote sensing in helping to solve problems faced by resource managers is discussed. Resource managers should take advantage of remote sensing developments which can provide useful, reliable data. The remote sensing community, on the other hand, should understand the problems managers have in underwriting the risks and costs involved in new developments.

L'auteur traite de rôle de la télédétection pour aider à résoudre les problèmes confrontés par les gestionnaires des ressources. Ces derniers devraient profiter des développements de la télédétection qui peuvent fournir des données fiables et utiles. Le monde de la télédétection, d'autre part, devrait comprendre les problèmes des gestionnaires en partageant les risques et les coûts que comportent les nouveaux développements.

INTRODUCTION

I have been asked by the members of the program committee of this symposium to try to explain why remote sensing is, or should be, used in resource management. Furthermore, I am to do this from the point of view of someone involved in remote sensing. The implication is that those who have once worked on remote sensing projects look at the world from a different perspective and are perhaps members of a different species. Fortunately, if one is to judge by the numbers taking part in this symposium, we do not seem to belong to an endangered species; however, we are clearly outnumbered by resource managers. These managers face immense problems, and we in the remote sensing community can assist in solving them.

One of the foremost problems facing resource managers today involves land use and the conflicting pressures for control of land. For example, in Ontario we are all aware of the challenges posed to resource managers by urban sprawl, and by increasing demands for land. There are huge increases in the price of land and there are controversies about its ownership. There are questions about how it is being used and what condition it is in. These and many other questions add up to an immense demand for information, and it is this demand which remote sensing can help to satisfy. A prime example of a large information system related to resource management is LACIE (Large Area Crop Inventory Experiment) in the United States, in which the current status of major crops, such as wheat, is monitored on a global scale. LANDSAT and other remote sensing systems are used to estimate the areas covered by different crops and to assess their condition. The information absorbed by the project includes data from meteorological satellites which, when combined with historical crop records and weather forecasts, permit the prediction of crop yields. The information from LACIE is linked with a huge econometric model which considers population statistics and transportation systems and permits an estimation of the economic and social impact of changes in harvest. LACIE is an excellent illustration of the fact that remote sensing is not an isolated aspect of resource management, but is an integral part of the management information system with strong links to the planning and operational aspects of management.

Another problem of the resource manager is the rapid change in costs and prices and the accompanying opportunities for profits and dangers of loss. Oil prices have increased since 1973 at a compound rate of 33%. What would happen if pulp were to rise another $100 per tonne--a very modest increase by OPEC standards?

A substantial increase in wood prices would immediately give rise to strong demands that neglected forest lands be put into production. Our first reaction would be one of frustration and anger, because it takes so long to grow a tree and because regeneration was neglected in the past. However, when we are told that Canada has at least 26 000 000 ha of "not satisfactorily restocked" forest land we should not complain but should consider ourselves far more fortunate than those who have to build mountain terraces or irrigation works in the desert in order to gain a few more hectares of productive land. We can start to manage our land immediately, and one of our first tasks should be to take stock of the available resource.

It is in this assessment of the resource that remote sensing can make its major contribution. Our general approach will be to use LANDSAT, combined with aerial photography and ground surveys. Aerial photography, however, is not only conventional photography at scales between 1:10 000 and 1:50 000. All the excitement about LANDSAT has caused managers and the research community to lose sight of the many developments of very small-scale photography. One photograph at 1:160 000 will cover approximately 100 times as much area as a standard Ontario Forest Resource Inventory photograph. It will not yield as much information but it can be, and has been, used for broad vegetation mapping and in environmental impact studies. Many resource managers have a special problem because of their success in the past. Perhaps they are responsible today for a planning, survey or inventory group which was the pride of the 1950s or 1960s. It is still reasonably efficient and produces reliable results. Why should they take risks with new methods and, in addition, incur the costs of retraining staff and of disrupting the status quo?

One reason is that we live in a very competitive world and our traditional resources will not be immune to the effects of this competition. There are, for example, the massive new pulpmill projects in the tropics, and the vast new agricultural programs in South America. Many of these are completely new programs in developing countries, where there is no cost involved in writing off an old system because everything is new. If staff have to be trained, they may as well be trained in the most recent methods, and if equipment has to be bought it may as well be the latest and best.

It is common to overestimate the effect of short-term changes and to underestimate the magnitude of long-term changes. If resource managers do not grasp some of the opportunities being offered by new technologies they will suddenly find themselves very far behind.

There are, however, ways of reducing the cost and the risks involved in changing to new technology. First, one should concentrate on the methods that are already well developed. Large-scale aerial photography and radar altimetry to replace much of the ground work in forest inventory are outstanding examples. A second approach is to make a conscious effort to apply new methods in new programs. There are many new programs in biophysical surveys, environmental studies and surveys for resource statistics. A baseline study for a northern pipeline or an assessment of the effects of acid rain are new programs. We should never transfer outdated methods to these new programs; rather, we should make every effort to employ the best technology. Since we will have to become acquainted with the new technology anyway, we may as well do so under circumstances in which already established systems do not have to be disrupted.

One of the perennial topics in the discussion of the relationship between resource managers and the remote sensing community is the so-called gap between the technical possibilities of remote sensing and the practical applications. In 1971, when a group of Canadians, including the chairman of this session, visited several NASA test sites and installations to learn about plans for an earth resources satellite it was told about this gap. There was to be no gap with LANDSAT; a major effort would be made to involve the resource managers and users. Although the gap has remained with us throughout the LANDSAT program it is smaller today than ever before, because we were given time to develop, to test and to prove the reliability of LANDSAT data interpretation. Almost seven years have passed since the launching of the first LANDSAT satellite, and few major technical changes in the satellite system have taken place in these years.

The topics to be discussed at the present symposium are similar to those you would have found five years ago, yet there is an immense difference. The results reported today are more reliable and have been achieved by methods that have undergone repeated tests. This afternoon, for example, you will hear a paper on forest type mapping from digital LANDSAT data; others on related topics will follow. There is a hidden message in these papers for the resource manager: reliable results of practical importance are being presented and the onus is now on you, the resource manager, to take what is being offered and to turn it to best advantage in the management of Ontario's resources.

Discussion

It was revealed that OCRS had recently acquired equipment capable of evaluating LANDSAT imagery, but it was pointed out that other forms of imagery must be evaluated as well.

PRINCIPLES OF REMOTE SENSING

U. Nielsen
Dendron Resource Surveys Ltd.
Ottawa, Ontario

This paper discusses the basics of remote sensing, from electromagnetic spectrum to satellite technology.

Ce document traite des principes de base de la télédétection, du spectre électromagnétique à la technologie des satellites.

INTRODUCTION

In remote sensing we have two major tasks. First, we must collect and record information on the objects of our interest. (This procedure is called "data acquisition".) Second, we must determine the significance of this information through the process of interpretation and classification. To prepare ourselves for these tasks we must review existing knowledge about objects that we want to detect and evaluate using remote sensing technology; then we must determine whether any of the information that can be recorded provides a measure of the objects that reliably distinguishes them from other objects in the same scene.

Because the interaction of energy and matter is object-specific, we can distinguish one object from another, and recognize specific objects and changes in their condition by interpreting recorded information.

THE ELECTROMAGNETIC SPECTRUM

Electromagnetic energy, of which the sun is by far the greatest source, is classified according to its wavelength into what is known as the "electromagnetic spectrum". Only a very narrow range in wavelength in this spectrum can be detected by the human eye, i.e., 400 to 700 nanometres. This visible part of the spectrum constitutes white light, which is a combination of the three primary colors: blue, green, and red. Electromagnetic energy with wavelengths shorter than those of visible light is divided into three regions: gamma, X-ray, and ultraviolet, in order of increasing wavelength. Beyond the visible spectrum are the near infrared, thermal infrared, radar, and passive microwave regions, only the first of which can be recorded using conventional cameras and some types of photographic film.

There is great interest in the near infrared region of the spectrum because of the relatively high reflectance of vegetation in this range (Fig. 1) and the consequent potential to distinguish vegetation from other objects. The difference in reflectance between healthy and damaged or stressed vegetation which exhibits a reduced reflectance may become useful in mapping devastation by insects, disease or drought.

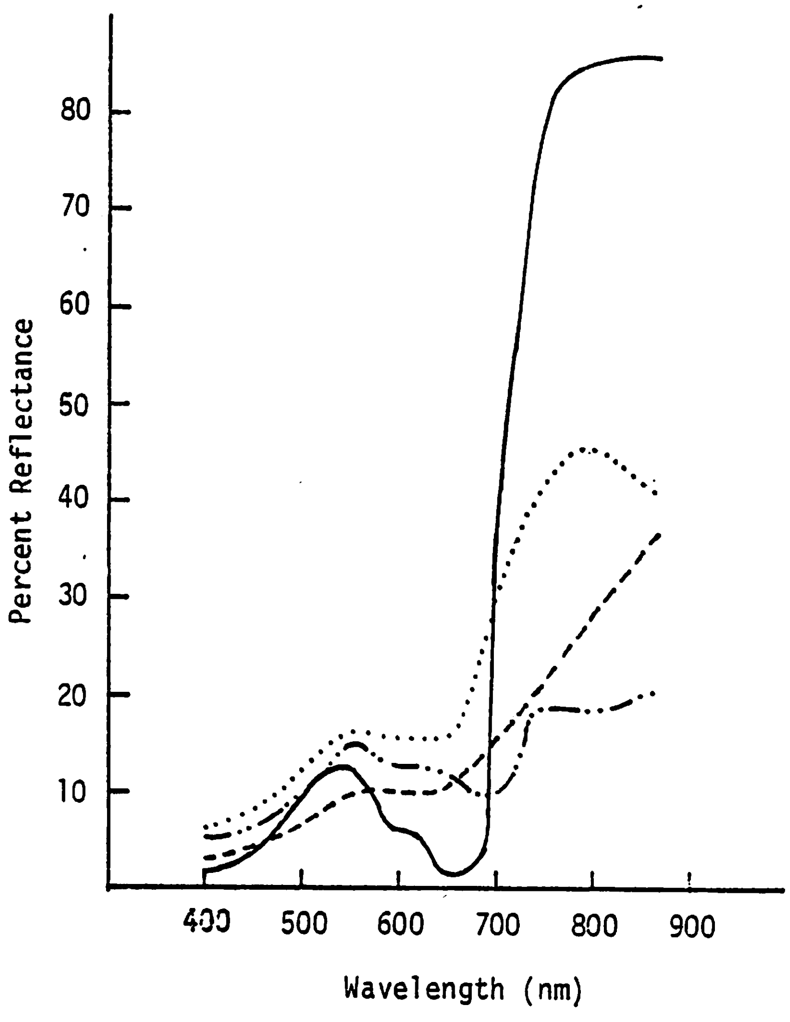


Fig. 1. Spectral reflectance curves of grass and several tree species.

Figure 2 shows how different colors in nature or "scenes" are reproduced by regular and color-infrared films, and presents the four corresponding LANDSAT bands.

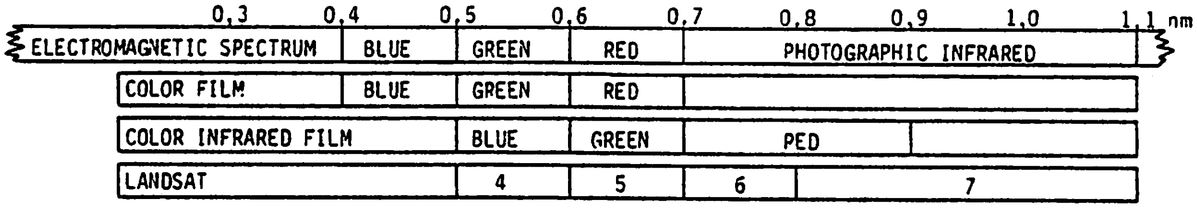


Fig. 2. Simplified sketch showing part of the spectrum (0.4 to 0.7 nm is the visible), the way in which different portions or bands are reproduced by normal and color-infrared films, and the correspondence of the four LANDSAT bands.

THE LANDSAT SATELLITE SERIES

The first satellite in this series, launched in 1972, is now inoperable; however, LANDSAT 2 and 3 are still functioning. Both satellites orbit the earth in such a manner that they alternately cover the same point on the earth every nine days. The satellites have two main sensors on board, a return beam vidicon camera (RBV) and a multispectral scanner (MSS). Computer-compatible tapes (CCTs) of RBV data are not yet available on an operational basis, and nearly all LANDSAT data that have been processed so far have been from the MSS.

The MSS consists of a mirror which rotates in the direction normal to the forward motion of the satellite. The mirror focuses the electromagnetic energy reflected by the scenes onto detectors. These signals are modulated by the intensity of the incoming radiation. After certain transformations, the data are telemetred to a ground receiving station where they are again subjected to transformations. The end result is a series of numbers, one for each resolution element of the scanner (pixel), which represents about 0.4 ha on the ground. These numbers are a measure of the intensity of reflected electromagnetic energy reaching the sensors and can be compared to the density of a photographic emulsion. For example, clean water is a good absorber of electromagnetic energy and will appear dark on a photographic emulsion, while snow is a good reflector and will appear very light. On LANDSAT, water will be represented by a very low number while snow will be represented by a high number. If we know that a certain number in a certain place represents water, snow, a particular kind of tree, etc., we can look for the same or similar numbers and we should, in theory, be able to separate all items represented by those numbers from the rest of the data. This is not always easy because conditions may make two different objects appear alike (same density on photo or same number on satellite data) or, conversely, like objects may appear different. To minimize incorrect classifications, LANDSAT offers four different sets of data (bands) which can be combined. Figure 3 is a printout of a thematic map which was classified by a computer using data from all four bands. In addition to this multiband capability, today's image interpretation systems permit the combination of data of different dates (multidate), and this increases the accuracy of classifications even further.

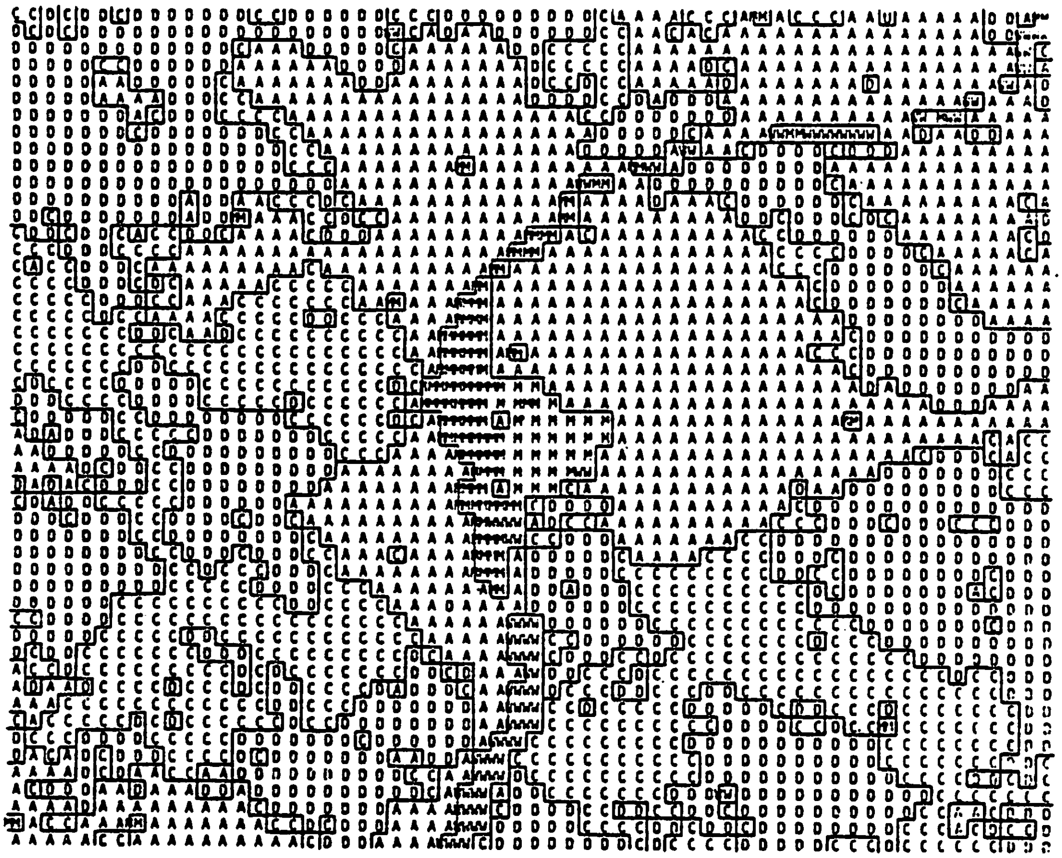


Fig. 3. Computer printout from classified LANDSAT data. Each letter represents one pixel (approximately 0.4 ha on the ground). A = agricultural land, C = coniferous forest, D = deciduous forest, M = bare soil and silted water, W = water, U = unclassified (from Kalensky and Scherk 1975).

The representation of computer-processed data as a printout, as shown in Figure 3, is not practicable because 2500 such pages would be required to display one scene (Kalensky and Scherk 1975). Special instruments are used to project a very small light beam onto photographic film. This beam, which is modulated by the numbers in the CCT, scans the film, producing upon completion a picture similar to that obtained using conventional photography.

Digital classifications fall into two major categories: unsupervised and supervised.

In the unsupervised classification, which is often aided by "enhancements" (i.e., by increasing contrasts or by enhancing certain features in some other way), the image is classified by number. A very simple example is as follows:

- numbers 10-30 will be represented in blue
- numbers 31-50 will be represented in green
- etc.

This classification is used when no field information is available. After an image has been classified, each class or color is labelled, either on the basis of field work or by using other means such as aerial photography.

A prerequisite for the supervised classification is some knowledge of what each number represents. For example, if we know that numbers 45 to 55 plus or minus a certain statistical measure correspond to coniferous trees, we can "train" the computer to recognize this fact, and we can ask it to retrieve this information from the rest of the image.

The precision of supervised digital classifications applied to separate classes such as agriculture, urban areas, water, other non-forested areas, conifers, deciduous trees and mixedwoods has improved steadily over the years because of improvements in equipment and software. At present, accuracies of 80 to 90% can be achieved consistently. This will probably be improved further as satellites with higher resolution and even better equipment become available. Two satellites are particularly worth mentioning: the next generation of LANDSAT, which will have twice the resolution (two LANDSAT satellites are scheduled to be launched in 1981-1982) and SPOT, a French satellite which will have a nominal resolution of 10 by 10 m.

LITERATURE CITED

Kalensky, Z. and Scherk, L.R. 1975. Accuracy of forest mapping from LANDSAT computer compatible tapes. p. 1159-1163 *in* Proc. Tenth Internat. Symp. on Remote Sensing of the Environment, Ann Arbor, Mich.

ONTARIO AND THE NATIONAL REMOTE SENSING PROGRAM

L.W. Morley, Director General
Canada Centre for Remote Sensing
Department of Energy, Mines and Resources
Ottawa, Ontario

The potential of remote sensing for supplementing aerial photography in resource and environmental management was first recognized by American scientists in the early 1960s. The Canada Centre for Remote Sensing was established a decade later to handle data from NASA's Experimental Earth Resources Technology Satellite. One of the most important recent developments has been the digital analysis of raster data. No conflicts are anticipated between federal and provincial remote sensing centres, as each has a well defined mandate.

C'est au début des années 1960 que les savants américains ont d'abord reconnu le potentiel de la télédétection comme appui à la photographie aérienne en matière de gestion des ressources et de l'environnement. Dix ans plus tard le Centre canadien de télédétection était établi pour le traitement des données transmises par le satellite expérimental de la NASA sur la technologie des ressources terrestres. L'un des plus importants développements récents a été l'analyse numérique des données de la trame. On ne prévoit aucun conflit entre les centres fédéraux et provinciaux de télédétection, étant donné que chacun d'eux a un mandat bien défini.

Remote sensing is an American technology with a military origin. It was used initially in the U-2 spy planes, spy satellites and infrared scanners. In the early 1960s the potential of remote sensing as a supplement to aerial photography in resource and environmental mapping was recognized by American scientists who had access to the technology.

The first unclassified remote sensing conference was organized by the Willow Run Laboratories at the University of Michigan in Ann Arbor in 1963. I was among the representatives of the Canadian government who attended that meeting, and we realized how important remote sensing would be for Canada. We spent the next eight years trying to convince the authorities that a remote sensing centre should be established in Canada. The idea was finally accepted when NASA announced that its experimental Earth Resources Technology Satellite (ERTS), now known as LANDSAT, was to be launched in 1972.

We proposed to NASA that we read out ERTS data at Prince Albert from a surplus radar antenna for which the Defence Research Board had no further use. NASA officials did not encourage this at first because they had planned to record all data on board the satellite and distribute it from the United States. They said that it was foolish for Canada to spend so much money on a ground data handling centre for an experiment. We persisted, however, and with high level diplomatic pressure we finally obtained an agreement and built our data handling centre.

During the planning stages in 1970 and 1971 we realized that this satellite would be gathering an enormous amount of data and that, unless we organized an army of users, these data would be wasted. We therefore arranged meetings with all the provinces to solicit their help. I remember being very discouraged at the meeting in Toronto in 1971 because there seemed to be little interest. Fortunately, a forester by the name of Victor Zsilinszky was present at the meeting. His background in photogrammetry enabled him to recognize the potential of this technology, and he was instrumental in promoting the establishment of the Ontario Centre for Remote Sensing. Incidentally, I learned last night that it was only by a fluke that he attended the meeting. He hadn't heard about it and someone invited him at the last moment.

In the early 1970s we thought that the chief method of interpretation was going to be "eye-balling" the imagery. However, General Electric produced a device they called the Image 100 which was capable of digitally analyzing the raster data. The Canada Centre for Remote Sensing was General Electric's first customer, and we were therefore among the leaders in the use of this technology.

The concept of digitally analyzing a raster scan is perhaps a more important breakthrough than remote sensing itself. It is revolutionizing information systems for resource management and environmental control. The system has the potential for injecting and overlaying any other kind of information instantaneously--airborne remote sensing, topographic information, ground truth mapping, weather and climate data, soil and soil moisture data, geological data, etc. Most important, it can overlay historical data, thereby making change detection possible.

I am happy to say that there are at least three Canadian companies--OVAAC-8 in Toronto, DIPIX in Ottawa and MDA in Vancouver--pioneering this technology. They are selling their systems around the world, and are involved in the development of other systems. We shall hear more about this when Dr. Strome presents his paper on Integrated Regional Resource Information Centres.

We see no conflict in mandate between the Canada Centre for Remote Sensing and the provincial centres. The latter have plenty to do in interpreting their own data and in attempting to provide real-time analysis, i.e., interpretation within hours of obtaining the data. This is a concept foreign to resource management because before now it was not possible. The full implications of such analysis are only now beginning to be realized.

At the Canada Centre for Remote Sensing we are concerned with receiving, processing and disseminating satellite and airborne data. We are negotiating agreements with NASA and other foreign space agencies to receive, process and disseminate their remote sensing satellite data. We are doing research on the analysis of data and on new sensors, and we are engaged in assisting the Canadian International Development Agency (CIDA) in foreign aid work in Africa, the Far East and South America.

SESSION II

Thematic Mapping

Chairman: D. Bates
Ontario Centre for Remote Sensing
Ontario Ministry of Natural Resources
Toronto, Ontario

BACKGROUND TO DIGITAL CLASSIFICATION AND ENHANCEMENT TECHNIQUES

E. Wedler
Ontario Centre for Remote Sensing
Ontario Ministry of Natural Resources
Toronto, Ontario

This paper is a brief introduction to digital imagery. Both image classification and enhancement techniques are described.

Ce document constitue une brève introduction à l'interprétation d'images numériques. Il décrit tant la classification des images que les techniques de rehaussement.

There are two basic types of images--analogue and digital. An example of analogue imagery is airborne photography, as shown in Figure 1[1]. Analogue images are characterized by a continuous grey tone. An example of a digital image is the LANDSAT scene shown in Figure 2, characterized by set levels of grey tones and resolution cells of a certain size.

Because this brief paper concentrates on *digital* imagery and provides an introduction to the topic, the terms "bit" and "pixel" should be explained. Figure 3 contains six digital images, labelled A to F, and shows how an image is composed of bits and pixels.

Bits (*bi*nary digi*ts*) are related to the grey tone levels in an image. The reason bits are assigned to grey tone levels is that digital computers work in the binary number system. Table 1 relates grey tone levels to binary digits. A one-bit image (Figure 3, images A and B) contains two grey tones--black and white. A two-bit image (Figure 3, images C and D) and a three-bit image (Figure 3, images E and F) contain four and eight grey tone levels, respectively, ranging between black and white. The greater the number of bits making up an image the greater its "grey tone resolution". An N-bit image has a grey tone resolution of 2^N grey tones. The LANDSAT scene in Figure 2 is a six-bit image; that is, it is composed of 64 grey tone levels.

---

[1] Interested parties may obtain prints of the photographs used to illustrate this paper by contacting the author.

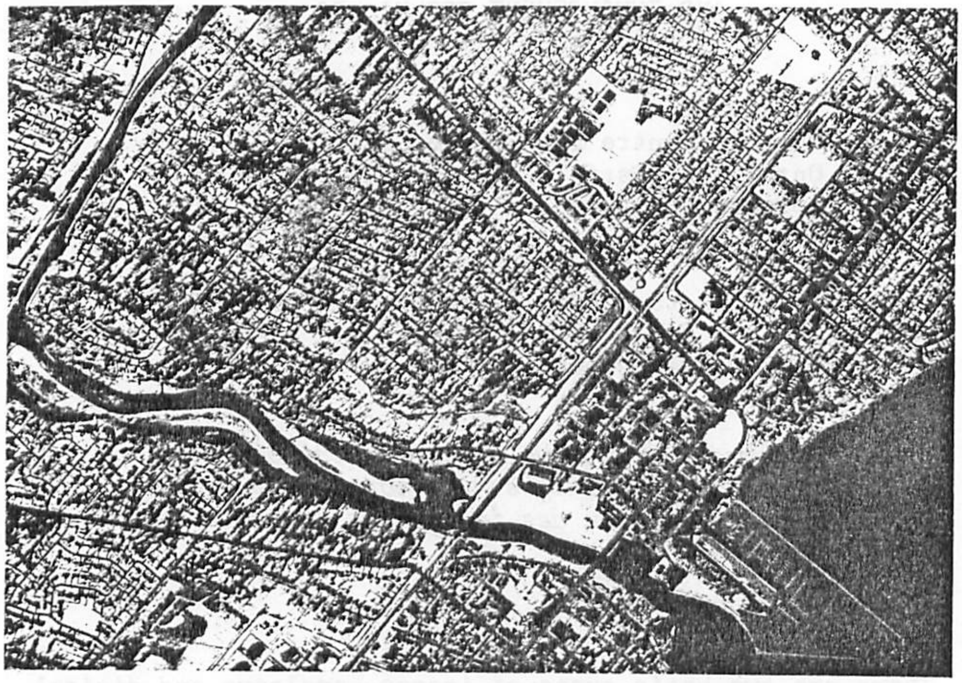


Fig. 1. An analogue image.

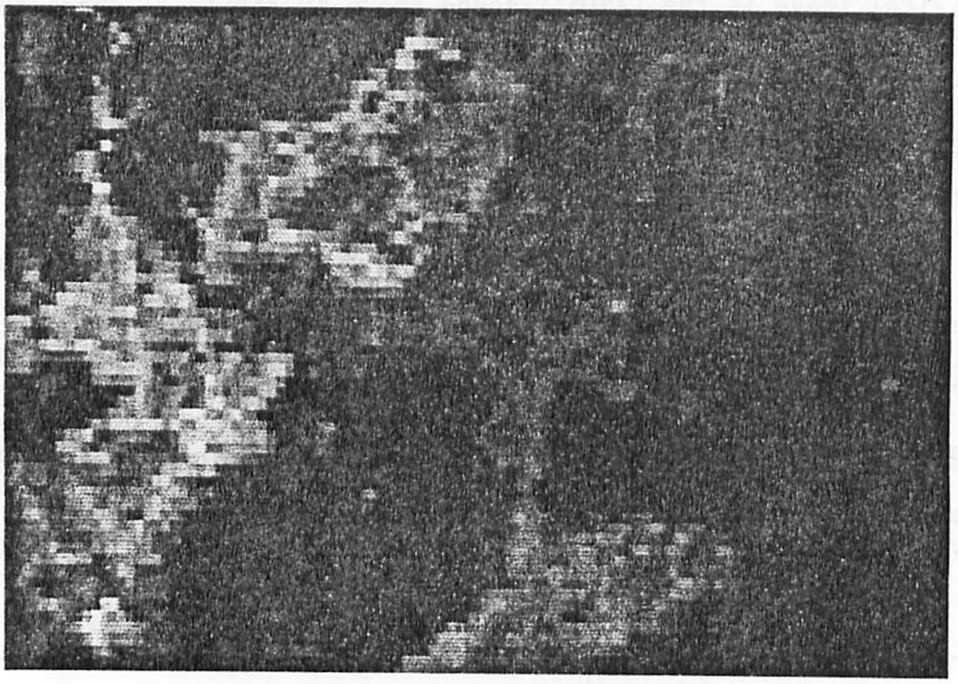


Fig. 2. A digital image.

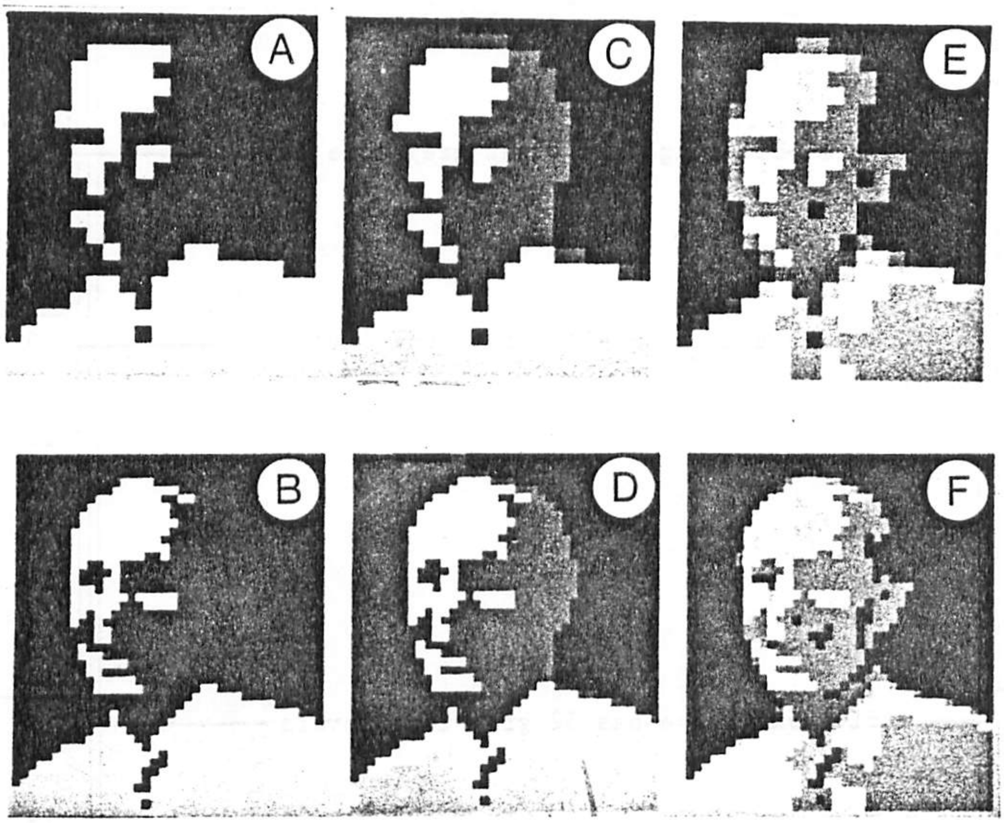


Fig. 3. Digital representation of an image (from Optronics Journal, September 1979).

The term *pixel* is an acronym for "*pi*cture *el*ement". A pixel is the smallest cell, or building block, which forms the image. Images A, C and E in Figure 3 each contain pixels of the same size. These three images are formed from a matrix to pixels 19 in the horizontal direction and 22 in the vertical direction. The bottom three images (B, D, and F) in Figure 3 are formed from a matrix of 38 x 44 pixels--a resolution four times finer than that in the top three images. The LANDSAT scene in Figure 2 is made up of a matrix of about 2,300 x 3,200 pixels, each pixel representing about 76 m x 59 m on the earth's surface.

Now that we understand what constitutes an image we can describe digital image classification and enhancement techniques. Both classification and enhancement of images are used to extract information of interest to the user. Some users may simply want to see more detail in a relatively featureless area and will use enhancement techniques to provide a greater level of detail. Others may want to delineate a crop type automatically with a high level of accuracy and will use classification

Binary digit		Image grey tone levels
0	A one-bit image has two grey tone levels	1
1	A two-bit image has four grey tone levels	2
10		3
11		4
100	A three-bit image has eight grey tone levels	5
101		6
110		7
111		8
1000	A four-bit image has 16 grey tone levels	9
1001		10
1010		11
1011		12
1100		13
1101		14
1110		15
1111		16
10000	A five-bit image has 32 grey tone levels	17
10001		18
10010		19
10011		20
10100		21
10101		22
10110		23
10111		24
11000		25
11001		26
11010		27
11011		28
11100		29
11101		30
11110		31
11111		32
•	A six-bit image has 64 grey tone levels	•
•		•
•		•
111111		64

Table 1. Relationship between bit number and image grey tone levels.

techniques to separate the crop of interest from other features. Both image classification and enhancement alter the appearance of the original image by manipulating the original pixel grey tone values, size or position. A classified image will group pixels with statistically similar characteristics and assign to each group a tone or color. The grouped pixels can represent terrain groups, such as water, deciduous vegetation, urban areas, etc. Figure 4 is a classified LANDSAT scene in which similar tones (colors) represent similar features. An enhanced image manipulates pixels in such a way that the image will appear to be *visually* more informative. Figure 5 illustrates an original and an enhanced LANDSAT image.

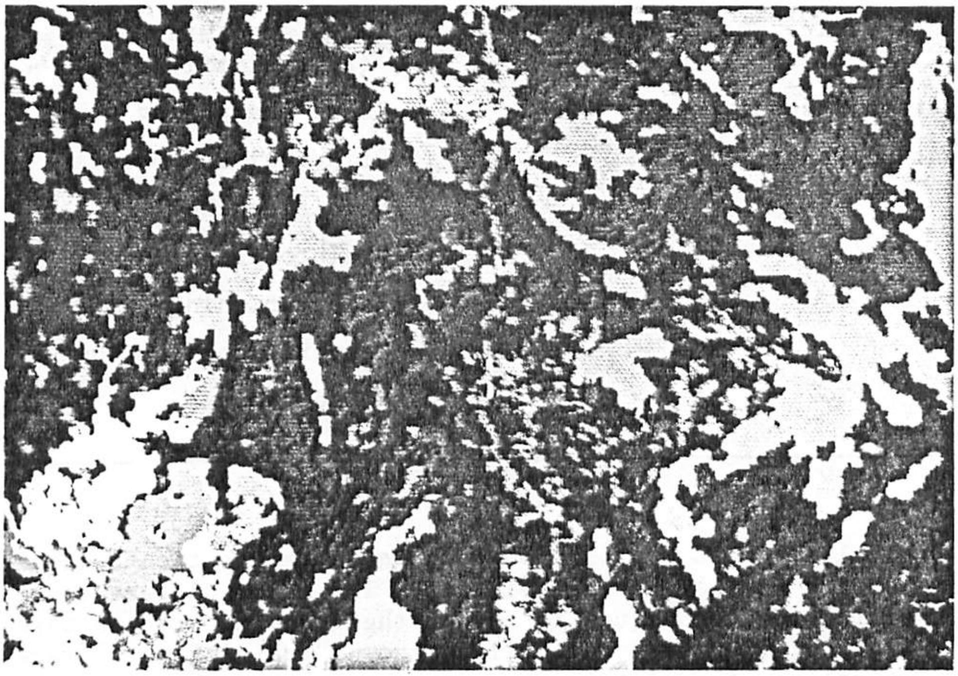


Fig. 4. Maximum likelihood classification of a LANDSAT image.

Various techniques are used in the classification and enhancement of digital imagery. Some of these techniques are listed in Table 2. This list is by no means comprehensive, as new techniques are continually being developed. Before any classification or enhancement of an image is used, preprocessing is performed. Preprocessing of digital imagery is done, for example, to remove "noisy" pixels or to re-format the image to a geometric base--in other words, to prepare the image for digital analysis. Some users consider preprocessing a form of digital image enhancement.

Table 2. A brief list of some digital image classification and enhancement techniques.

Digital image classification	Digital image enhancement
. Maximum likelihood	. Density slicing
. Quadratic decision	. Edge enhancement
. Linear discriminant functions	. Change detection
. Composite sequential clustering	. Contrast stretching
. Elliptical boundary condition model	. Non-linear radio metric enhancement
. Non-parametric partitioning	. Image smoothing (spatial filtering)
. Supervised/unsupervised	. Image sharpening
. Nearest neighbor	. Principal components
	. Magnification
	. Skeletonizing
	. Band rationing
	. Temporal combinations
	. Noise removal

Digital image *classification* techniques, as mentioned earlier, group pixels with similar characteristics. The major difference between these classification techniques is in how the grouping process takes place. The grouping process may utilize known "training sets" (areas with known pixel characteristics) to sort pixels into themes, or "natural clusters" of pixels to sort pixels into themes. The purpose of image classification is to assist a user in rapidly, and perhaps automatically, extracting features of interest.

Digital image *enhancement* techniques, as mentioned earlier, manipulate pixels to enhance an image visually. The enhancement may be tonal or spatial. The features that become enhanced depend on the technique used. If linears are to be enhanced, for example, edge enhancement or contrast stretching may be considered. The purpose of image enhancement is to assist a user in interpreting an image visually.

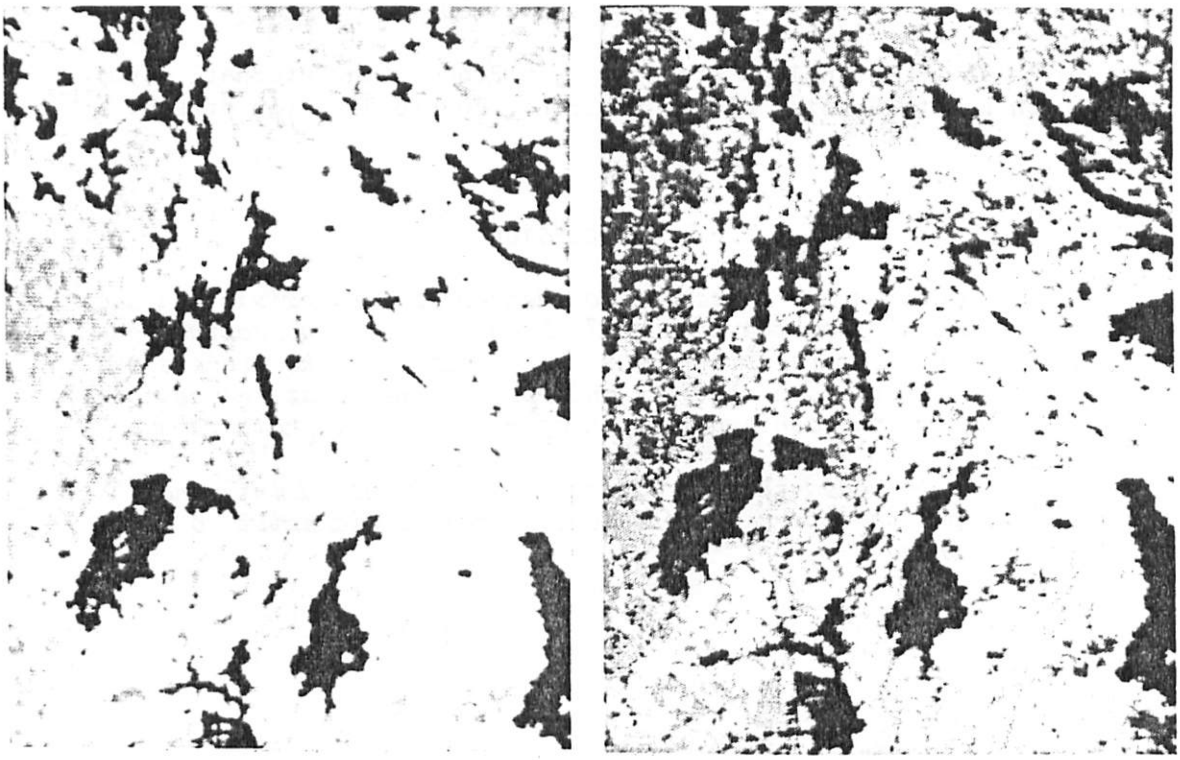


Fig. 5. An original LANDSAT scene (left) and an enhanced LANDSAT scene (right).

A question often raised is: "Which of the two digital analysis methods is better?" The answer to that question depends on the application being considered. Image enhancement is often more economical than image classification when the operations to be performed are well established and understood. Classification, however, is quantitatively more informative than enhancements since pixels grouped into themes can be more easily measured, and themes quantified.

The information presented in this paper provides only a small insight into a very large field of investigation. Although digital techniques have been described, other optical and analogue techniques exist as well, but they are outside the scope of the paper. The Ontario Centre for Remote Sensing uses digital image analysis software and equipment for studies on LANDSAT, radar and other imagery in various applications. Through technology transfer programs that are being implemented at the Centre (Pala 1980) and elsewhere in Canada, an introduction to digital analysis techniques is available to users of remote sensing data.

LITERATURE CITED

Pala, S. 1980. Technology transfer. *In* Proc. 14th Internatl. Symp. on Remote Sensing of the Environ., Puerto Rico (in press).

Discussion

The question was raised as to whether feature extraction and removal of "noise" from the data could be considered subjective manipulation which might result in biased information. The process was termed "honest", provided that the interpreter knew what he was doing. It was likened to photointerpretation of conventional photography.

It was conceded that variation in terrain could influence the pixel values but that terrain modification models did exist to deal with this influence.

FOREST TYPING FROM DIGITIZED LANDSAT IMAGES IN QUEBEC

J. Beaubien, Research Scientist
Department of the Environment
Canadian Forestry Service
Laurentian Forest Research Centre
Ste-Foy, Quebec

This paper describes a three-year project begun in the spring of 1978 on Quebec's North Shore, prior to hydroelectric installations, for the purpose of classifying forest types over roughly 200 000 km^2 *within the framework of an ecological land classification. Digital color enhancement and the supervised classification methods used are described and discussed.*

Cet article décrit un projet triennal qui a vu le jour au printemps 1978 sur la Côte Nord du Québec, avant la mise en place des installations hydroélectriques, aux fins de classifier les types de forêt d'une superficie d'environ 200 000 km^2*, dans le cadre d'une classification écologique des terres. Le rehaussement des couleurs au toucher ainsi que des méthodes de classification sous supervision sont décrits et traités.*

INTRODUCTION

Since the launching of the first satellite in July 1972, there have been many successful applications of the transmitted data to resource inventories. Forest inventory applications, though numerous, have had highly variable results. I will cite only a few recent Canadian studies that have been successful: Kirby and Van Eck (1977), Lee (1977), Cihlar et al. (1978), Kourtz and Scott (1978), Rubec and Wickware (1978) and Kalensky et al. (1979).

One of the latest studies in Quebec was undertaken on the Laurentian plateau, a hilly region covered by a very diversified vegetation (Beaubien 1978). Unsupervised digital classifications distinguished hardwood stands, mixed stands, and two or three types of softwood stands, depending on the area concerned. Apart from taxonomic categories, the factors which played the largest role in softwood class distributions were age, density, degree and exposure of slopes. It was impossible to distinguish regeneration and mature stands within mixed or hardwood forest types. The study showed that data obtained by satellite can provide information needed for a general mapping of forest vegetation cover.

This paper describes a 3-year project begun in the spring of 1978 on Quebec's North Shore (57°-68° W, 50°-53° N) (Fig. 1), prior to hydroelectric installations, for the purpose of classifying forest types over roughly 200 000 km^2 within the framework of an ecological land classification. Thus far 50 000 km^2 have been mapped using five summer LANDSAT images recorded on different dates.

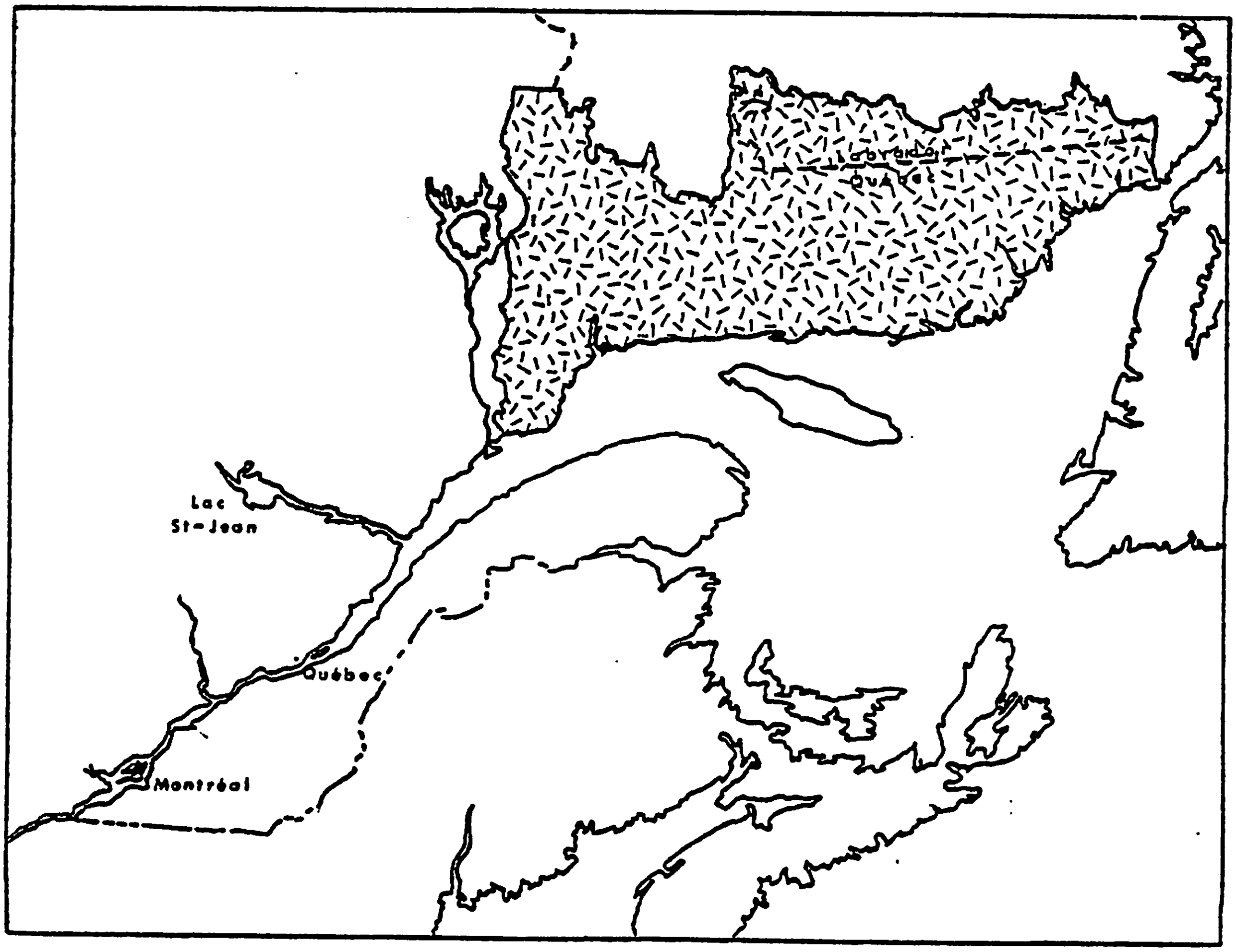


Fig. 1. Location of studied area on Quebec's North Shore. Scale 1:9 000 000.

The forest vegetation is composed mainly of softwood--balsam fir (*Abies balsamea* [L.] Mill.) and black spruce (*Picea mariana* [Mill.] B.S.P.)--growing in pure or mixed stands. Stand densities are very variable depending on soils, altitude and latitude. North of the 52nd parallel the forest is more open, with a cover of lichen, open black spruce stands and various kinds of tundra. The area has been devastated by many forest fires, and the burnt areas are now occupied by a large variety of cover types: broadleaf stands, mixed stands, shrub tundra and rock barrens.

METHODS

The LANDSAT digital data from computer-compatible tapes are processed by means of "ARIES" (Applied Resource Image Exploitation System), the development of which was funded by the Canadian Forestry Service. The first step consists in enhancing the images by choosing the three principal color components (Kourtz and Scott 1978). The selected image enhancements are then subdivided, recorded through a DICOMED digital image recorder on a 70 mm color positive film, and printed so as to obtain a scale of approximately 1:250 000. The prints are used in the field to correlate the various colors with ground covers observed from a small aircraft or helicopter. Sample plots are described from the air in terms of cover type, percentage of each species and density of the stand when applicable. These data are compiled and a vegetation key is made that relates to the various colors of each frame enhancement. Later, supervised classifications can be performed or vegetation mapping can be done directly by interpreting the enhancements through the 70 mm color transparencies projected on a translucent surface with adjustment for the desired scale. If precise mapping is needed, the data can be corrected geometrically before recording.

RESULTS AND DISCUSSION

Mapping of the 50 000 km^2 area already completed was done mainly at the scale of 1:125 000 through the interpretation of enhanced pictures; only one frame was classified by means of supervised classification. The following classes were identified and evaluated as components of a pattern in each unit (maximum of three vegetation types per unit):

- dense softwood (density 50% and +)
- open softwood (density 25-50%)
- open lichen-softwood (density 25-50%)
- mixedwoods
- hardwood
- shrub-forested heath (density 10-25%)
- lichen forested heath (density 10-25%)
- shrub heath (density 10% and -)

- lichen heath (density 10% and -)
- open peatland (bogs and string bogs)
- recent burns

The greatest problem was that of distinguishing shrub-forested heath and shrub heaths of string bogs and bogs, respectively, by means of color enhancement techniques. However, these distinctions were possible with supervised classifications based on ground truthed data.

We are not yet satisfied with density estimation of softwood stands, but recently improved enhancements were obtained using other components.

We have investigated supervised and unsupervised classifications, and color enhancement. Unsupervised classification can be effective in separating the main cover types for which information is needed before ground truthed data are collected. On the output color pictures illustrating several classes, planimetric details such as vegetation transitions, lakes and roads are not very apparent. A good color enhancement can be more useful for field work because these details appear more clearly. In the field enhancements are used like color aerial photographs. However, supervised classifications seem necessary to distinguish certain specific ground covers with reflectances near one another.

By choosing the appropriate training areas to form the components of an image, the operator is able to enhance specific ground cover types at the expense of other cover types. For a general enhancement before field work, the first component (brightness) should come from general training areas, including the majority of the features of interest. However, we did not find a "recipe" that could be used consistently; each image must be treated individually to obtain maximum information. When one is dealing with a large area that includes more than one frame, this is an important problem because each frame processed and ground checked individually must be linked afterwards with the other frames.

Despite the preliminary nature of the results, LANDSAT technology can provide information needed for valuable mapping of forest vegetation over large areas. Our present maps can be compared with the synthetic maps produced by the Quebec Department of Lands and Forests from a generalization of the conventional forest maps (1:20 000). We should give serious consideration to making wider use of LANDSAT data, especially for vegetation classification of remote areas. Satellite data can reduce the cost of forest inventories considerably when general information is sufficient, and can provide a first stratification to serve as a guide for more detailed surveys. The approximate cost of classifying and mapping a 200 000 km^2 area, at a scale of 1:25 000, including material, computer and operator time, field work and cartography, is $145,000. Mapping the same area from conventional aerial photographs (scale 1:15 000 - 20 000) would cost $2,200,000, including aerial photography, field sampling, photointerpretation and cartography. Of course, the two sets of maps are not comparable as far as precision is concerned, but would the information extracted from LANDSAT not be sufficient for our northern territories where management and harvesting will not be required in the near future?

The potential of remote sensing by satellite will be realized more fully when new satellites and classification algorythms have been improved.

LITERATURE CITED

Beaubien, J. 1978. Forest type mapping from satellites, six years after. p. 7-15 *in* Proc. Fifth Can. Symp. on Remote Sensing, Victoria, B.C.

Cihlar, J., Thompson, D.C., and Klassen, G.H. 1978. Mapping vegetation at 1:1 million from LANDSAT imagery. p. 427-440 *in* Proc. Fifth Can. Symp. on Remote Sensing, Victoria, B.C.

Kalensky, Z.D., Moore, W.C., Campbell, G.A., Wilson, D.A., and Scott, A.J. 1979. Forest statistics by ARIES classification of LANDSAT multispectral images in northern Canada. *In* Proc. 13th Internatl. Symp. on Remote Sensing of the Environ., Ann Arbor, Mich. (in press).

Kirby, C.L. and Van Eck, P. 1977. A basis for multistage forest inventory in the boreal forest region. p. 71-94 *in* Proc. Fourth Can. Symp. on Remote Sensing, Quebec, Que.

Kourtz, P.A. and Scott, A.J. 1978. An improved image enhancement technique and its application to forest fire management. p. 72-78 *in* Proc. Fifth Can. Symp. on Remote Sensing, Victoria, B.C.

Lee, Y.J. 1977. Computer-assisted forest land classification by means of several classification methods in the CCRS Image-100. p. 37-46 *in* Proc. Fourth Can. Symp. on Remote Sensing, Quebec, Que.

Rubec, C.D. and Wickware, G.M. 1978. Automated land classification in the boreal zone using LANDSAT digital data. p. 127-135 *in* Proc. Fifth Can. Symp. on Remote Sensing, Victoria, B.C.

Discussion

In view of the prolonged and conflicting debate over the relative merits of supervised classification and image enhancement, it was decided to include a brief explanatory note rather than to synopsize the discussion.

Image Enhancement Versus Supervised Classification

Both enhancement and supervised classification attempt to identify patterns on an image. The patterns to be identified may be caused by diseased spruce, flooded farmlands, ploughed fields, harvested wheat, etc. The usefulness of the patterns is determined by the image interpreter.

Both can be considered an *art*, where techniques and standards are *unknown*, yet both can also be considered a *science*, in applications where *known* techniques and standards are used.

The table below, though not complete by any means, attempts to illustrate the differences in these approaches to analyzing images. There are advantages and disadvantages to both. The approach that is superior depends on the solution required of a particular task. For example, a seasonal inventory of prairie ponds by size class and distribution would undoubtedly be handled better by supervised classification. On the other hand, the rapid extraction of ice fractures in the arctic for tactical marine navigation would be better handled by enhancement.

	Enhancement	Supervised classification
Equipment	. optical and/or digital	. digital
Input	. analogue and/or digital	. digital
Output	. qualitative . greater grey-scale smoothness	. quantitative and/or qualitative . consistent and easily reproducible . loss of grey-scale smoothness (pixel blockiness)
Some procedures used	. removal of image noise and distortion . translation, rotation and scale change . edge sharpening . contouring . grey-scale level slicing . contrast stretching . filtering . color/band combinations (add, subtract, ratio, principal component)	. statistical feature extraction . feature detection based on statistical relationships, clusters and other decisions . image classification based on grouped features with boundaries defined
Analysis	. visual approach in interpretation . requires more exhaustive image calibration	. requires computer programs, algorythms . more easily reproducible . requires training sets of pixels

Comparison of the two approaches involves a number of debatable issues, among them the question of overlapping and undefined patterns or classes, cost, development, and setup time. Comparisons must take into consideration the particular task at hand, but one thing is certain: enhancements and supervised classifications distort the original data. The objective of the image interpreter should be to *control* the distortion so that he extracts useful information in a consistent, accurate and cost-effective manner.

A COMPREHENSIVE FOREST FUEL MAPPING FOR ONTARIO

S. Pala
Supervisor, Research and Training
Ontario Centre for Remote Sensing
Toronto, Ontario

This paper discusses the integration of forest fuel mapping based on satellite data into forest fire control field operations in Ontario. The information required in forest fire management is specified and the usefulness of existing LANDSAT data and analysis techniques in providing this information is evaluated. Efforts made by both the federal and the Ontario governments to transfer LANDSAT methodology to field fire control personnel are described. Finally, a procedure for effecting such a transfer is proposed and suggested as a model for the transfer of remote sensing technology in general.

Le présent document à trait a l'intégration du relevé cartographique des combustibles forestiers d'après les données transmises par satellite aux opérations de protection in situ contre les feux de forêts en Ontario. Les informations requises en matière de gestion des feux de forêts sont spécifiées et l'utilité des données LANDSAT existantes et des techniques d'analyse pour l'obtention de ces informations est évaluée. Les efforts faits tant par le gouvernement fédéral que par le gouvernement de l'Ontario pour transférer la méthodologie LANDSAT au personnel responsable in situ de la protection contre le feu sont décrits. Enfin, un procédé pour effectuer un tel transfert est proposé et suggéré comme modèle pour le transfert de la technologie de la télédétection en général.

PROBLEM

For precise assessment of forest fuel conditions, data would be required on the species composition, age, density, branching habit and moisture condition of the forest stands, as well as on the composition and moisture content of the understory, ground cover and soils. To predict the spread of a fire it would then be necessary to compute from these data the burning characteristics of the trees under each combination of conditions, taking into account atmospheric conditions, particularly wind speed and direction. However, even if it were possible to

---

NOTE: Apart from the flow chart (Fig. 1), no illustrations are included in this paper as they would be meaningful only in color. Anyone interested in obtaining color prints of the transparencies shown at the symposium may contact the author.

compile such comprehensive data for small sites, it would not be feasible to do so for the large areas over which forest fires may burn in northern Ontario. The best compromise is to compile as much information as can be obtained and make the best use of it.

The Ontario Forest Resources Inventory (FRI) program produces 1:15 840 scale forest stand maps from the interpretation of aerial photography, covering the entire province south of latitude 52°N, and revises them at 10-year intervals. In the case of small fires these maps and photographs are studied in the planning of fire-fighting strategy, but if the local fire-fighting personnel do not keep them up to date between 10-year revisions they may be of little value even for small fires, in which case the personal knowledge of experienced fire managers regarding local conditions is the only source of information available.

When a fire is extensive, however, the FRI data become too cumbersome to use because of the large number of maps and photos required to cover the area. If the maps, which are printed in black and white, are photographically reduced for convenience, it also becomes difficult to distinguish the individual stand boundaries because of the level of detail at which the stands are typed: even shorelines are obscured, and this makes orientation difficult. In addition, the stand maps must be colored according to forest protection priorities in order to provide a rapid overview of the fire, a time-consuming task which must be done in advance and continuously revised as forest conditions change. However trustworthy the personal knowledge of the field staff may be, it is unlikely to be complete for inaccessible areas. Nor is it possible for staff newly arrived in the district to have the necessary depth of experience of local conditions. Furthermore, the need for an overall assessment of fuel conditions is more urgent in the case of a large fire. Small fires that occur one by one are fought individually, but in the case of a large fire, decisions must be made as to the priority of attack points and the deployment of resources.

It is obvious that satellite imagery will not be able to provide all the information required to estimate the speed and direction of the advance of a forest fire. However, LANDSAT can provide data on forest types, cutovers, burns, blowdowns, wetlands and extensive diseased or infested forest areas that field personnel cannot obtain on a broad scale, or at short notice, in any other way.

THE INTRODUCTION OF SATELLITE DATA TO FOREST FUEL MAPPING

Forestry has been one of the disciplines to benefit most from the launching of earth-resources satellites. Multispectral scanner imagery has been successfully applied to the classification of broad forest types and the mapping of cutovers, burns and other forest disturbances. In pilot studies, the detailed mapping of selected stand types has been achieved. The large area covered by a single frame and the fact that repetitive coverage is available at a relatively short interval enable the forester to monitor changes in forest conditions, thereby integrating satellite data into his day-to-day work. Evidence of the value of these data indicates that their extensive and diversified use should be vigorously promoted.

The use of satellite data in forest fuel mapping was introduced by Dr. Peter Kourtz of the Forest Fire Research Institute (FFRI). Dr. Kourtz prepared a computer classification of LANDSAT for forest fuel mapping which identified the distribution and extent of various forest types. However, because the field fire control staff who received the classifications were unfamiliar with the jagged type boundaries inherent in a pixel-by-pixel analysis they did not accept this form of information in the mistaken belief that the boundaries were too imprecise to be useful.

To his credit, Dr. Kourtz did not abandon the idea but attempted to give the field staff a format with which they would be more comfortable, i.e., a presentation which resembled a photograph. He initiated the application of the principal-component enhancement technique, developed by Dr. M.M. Taylor of the Defence and Civil Institute of Environmental Medicine. The principal-component image enhancement technique heightens the apparent differences in selected reflectance values while minimizing the apparent differences in other reflectance values within a scene for the purpose of generating, in vivid colors, the presentation most pleasing to the eye. Image enhancement is a sophisticated art permitting a ready, visual recognition of the selected energy levels. The imagery thus produced appears to be like a photograph and the type boundaries appear generalized rather than in the form of individual pixels. During the first year, however, Dr. Kourtz had difficulty obtaining the quality of reproduction that he required.

Since 1978, Dr. Kourtz has produced very high-quality enhancements using ARIES hardware and software developed for the Forest Management Institute by Computer Devices of Canada (now named DIPIX Systems Ltd.). Enhancements have been provided for field fire control staff in Ontario and in other provinces.

DISCUSSIONS WITH FIELD FIRE CONTROL STAFF

In order to investigate how the use of satellite data by field fire control staff could be promoted, the author met with personnel of the Forest Fire Control Centre (FFCC) of the Ontario Ministry of Natural Resources (OMNR) to explore their reactions to the satellite data that had so far been provided for them.

It was estimated that, although 90% of the field fire control staff in Ontario are aware of the existence of LANDSAT data, and 20%

are familiar with the imagery products, only 10% of the staff have any understanding of the sensors and the nature of the data or are able to interpret them knowledgeably. It was estimated that only 1% of the field staff had any knowledge of the processes of enhancement and digital analysis.

One encouraging comment was made at the meeting, however. It was said that, although field personnel thought of LANDSAT images as "pretty pictures" and could find little significance in them, they were generally of the opinion that in the future satellite data would assist fire fighting substantially. This state of affairs is indicative of deficiency in the data available to the users or in their understanding of its use, or both.

To determine the adequacy of the data available to the Ontario field staff it is necessary to consider the applicability of each of the three forms of data so far available:

Computer classification - which was rejected by field managers

Image enhancement - which has been used with reservation

Normal color composite - which has received the least attention.

Computer Classification

The staff of the FFCC declare that knowledge of the *exact* quantity and type of forest stand in a burning area is a crucial factor in deciding forest fire-fighting strategy. Therefore, because of the precision with which it can be used to locate a given forest type and to estimate its area coverage, computer classification must form part of the satellite data package for fire control planning. A selective forest typing based on a supervised classification would provide sufficient data for this purpose. With this method it would also be possible to classify a district according to levels of fire hazard, on the basis of forest typing, for quick reference. The objections from field staff that the pixel form of type boundary is too imprecise may be overcome by an explanation that computer analysis of LANDSAT for forest typing is not intended to replace the FRI stand typing. For small fires, the imprecision of computer analysis might be significant but the computer analysis is not designed to be used for small fires, nor is it needed there. For large fires, the imprecision of type boundaries caused by the pixel-by-pixel format may be less significant in view of the size of area involved.

The unsupervised classification method is not recommended for this purpose. Although it would produce a detailed, colored presentation, the interpreter has the frustrating task of imposing his own generalization on areas that appear diverse because no thematic generalization is performed.

Color-enhanced Images

Ontario field fire control personnel have received color enhanced enlargements of segments of LANDSAT frames, at a scale of 1:100 000, from FFRI. Although the quality of this imagery is excellent, the frames are enlarged in segments and the color may vary slightly from one segment to another. This is unavoidable and can be ignored by anyone trained in both satellite data interpretation and photography. However, an untrained individual may be misled by the variation because he expects a particular color to be associated always with a particular feature or condition. From one frame to another of the same orbit and from one orbit path to another, recorded reflectance varies enormously but an enhancement technique that uses the same color-to-brightness gradient from frame to frame or orbit to orbit will present increasingly diverse conditions in the same color. Use of the supervised classification method can overcome this difficulty because the classifications are thematic rather than directly radiometric and the color representation can be adjusted from frame to frame according to changing radiometric reflection levels so that the same condition is always represented by the same color and the association of color with ground condition is reliably made.

The enhancement technique displays all the features with high reflectance values such as cutovers, burns, bogs, fens, marshes, agricultural lands and settlements in the same color but for fire control purposes it is extremely important to be able to distinguish between these features. Even within cut-over areas it is necessary to distinguish fresh cutovers with slash from older cutovers with regeneration. All of these features can be positively identified on the original color composite image. The enhancement process, however, distorts the recorded data, impeding interpretation rather than aiding it so that even an experienced interpreter is confused. It is essential, therefore, always to refer to the original color composite when using enhancements.

Normal Color Composite

The color composite, whether the original small-scale or enlarged, has received little attention from field fire control staff. Instead, staff have been given the results of interpretation of the original imagery made by others, and have not had an opportunity to gain an understanding of how those results were achieved or what they signify. Yet, in the normal color composite, variations in reflectance can be seen clearly and patterns that aid identification can be recognized. The most important advantage of the use of the color composite is that much finer distinctions in infrared reflectances can be made in the forest cover and visual distinctions can be made among cutovers, burns, wetlands, farm fields and settlements.

With respect to immediacy and ease of comprehension, computer classification is superior to image enhancement. However, neither technique can be understood or used successfully without a basic understanding of the original raw data. If the user is able to interpret the color composite he will be able to put either the enhancement or the classification to work and will not be restricted to one form of data simply because it is the only one familiar to him. He will be able to take advantage of whatever type of data exists for his area and, if there is more than one type available, he can use them all simultaneously. This is the best way to extract information on a given condition.

PROPOSED METHODOLOGY FOR LANDSAT USE

The disappointments experienced by field staff attempting to apply LANDSAT data can be avoided in future if they supplement the enhancement with the original color composite. Conditions that may be confusing on the enhancement can be clarified by referring to the original. When a computer classification is used, even though the color is consistent and confusion between cutovers, burns, bogs, etc., can therefore be avoided, it is necessary to study the original image in order to determine the conditions associated with each color. It is therefore suggested that field staff be advised of the importance of referring to the original color composite when interpreting either form of data and that they use the color composite as the primary data source when no classification or enhancement is available for the area of interest.

It is also suggested that whenever time and funds permit, the supervised classification be used rather than the enhancement because field staff require instant information on the distribution of individual features of interest, and a relatively precise delineation of types, for quantitative assessment in a form they can quickly comprehend.

TRAINING REQUIREMENTS FOR FIRE CONTROL STAFF

If the field staff who received satellite data had understood the basic concepts behind LANDSAT recording and the computer classification and image enhancement techniques, they would not have encountered difficulties in interpreting the data without the aid of the original color composite. Accurate interpretation of the original composite would also require that field personnel have an understanding of sensor characteristics and introductory training in the use of spaceborne data. It would therefore appear that an essential step in the process of technology transfer was neglected. Expecting field staff to put into practical use the product of this new and sophisticated technology without training them in the basics of spaceborne multispectral sensing is rather like giving someone a sophisticated calculator without an instruction manual. The field staff should not be accused of stubborn traditionalism because of their failure to apply the data as not even universities at the present time offer the practical, specialized training they require.

Ontario Centre for Remote Sensing (OCRS) Education Program

In an attempt to meet the needs of field staff, OCRS, in cooperation with FFCC, has established a program to train OMNR personnel responsible for fire strategy decisions in the interpretation of LANDSAT images. Each seminar will last less than a week and a maximum of 10 staff members per seminar will be trained. The seminar will have three main purposes:

1. to introduce the LANDSAT sensors and their recording characteristics and the available LANDSAT products
2. to provide in-depth experience in the visual interpretation of satellite data, in its original form, for the major forest types, cutovers, burns, blowdowns and various wetland types
3. to familiarize the participants with electro-optical and digital analysis by both enhancement techniques and classification methods.

The participants will perform hands-on exercises in visual interpretation and electronic analysis.

The first seminar in this series has been scheduled for November, 1979. Although the degree of its success cannot be known at this stage, members of the Ministry's fire-fighting staff who have received a similar introduction to LANDSAT in the context of other courses given by OCRS affirm that only through such training will field staff learn to apply the new technology and recognize its limitations. These seminars will continue until every fire management decision maker has been trained.

MODEL FOR REMOTE SENSING TECHNOLOGY TRANSFER

A systematic procedure should be followed in transferring remote sensing technology to the user. Once research and development have been completed, trial applications of the new methodology, in which a fairly simple form of spaceborne data is used, should be undertaken. Users must be familiar with the basic concepts and must be trained to understand and apply all available forms of spaceborne data before they can be expected to employ a sophisticated technology.

If trial applications are successful, a methodology for operational use should be established. If the trials are unsuccessful, however, the entire process of technology development and transfer should be re-examined (Fig. 1).

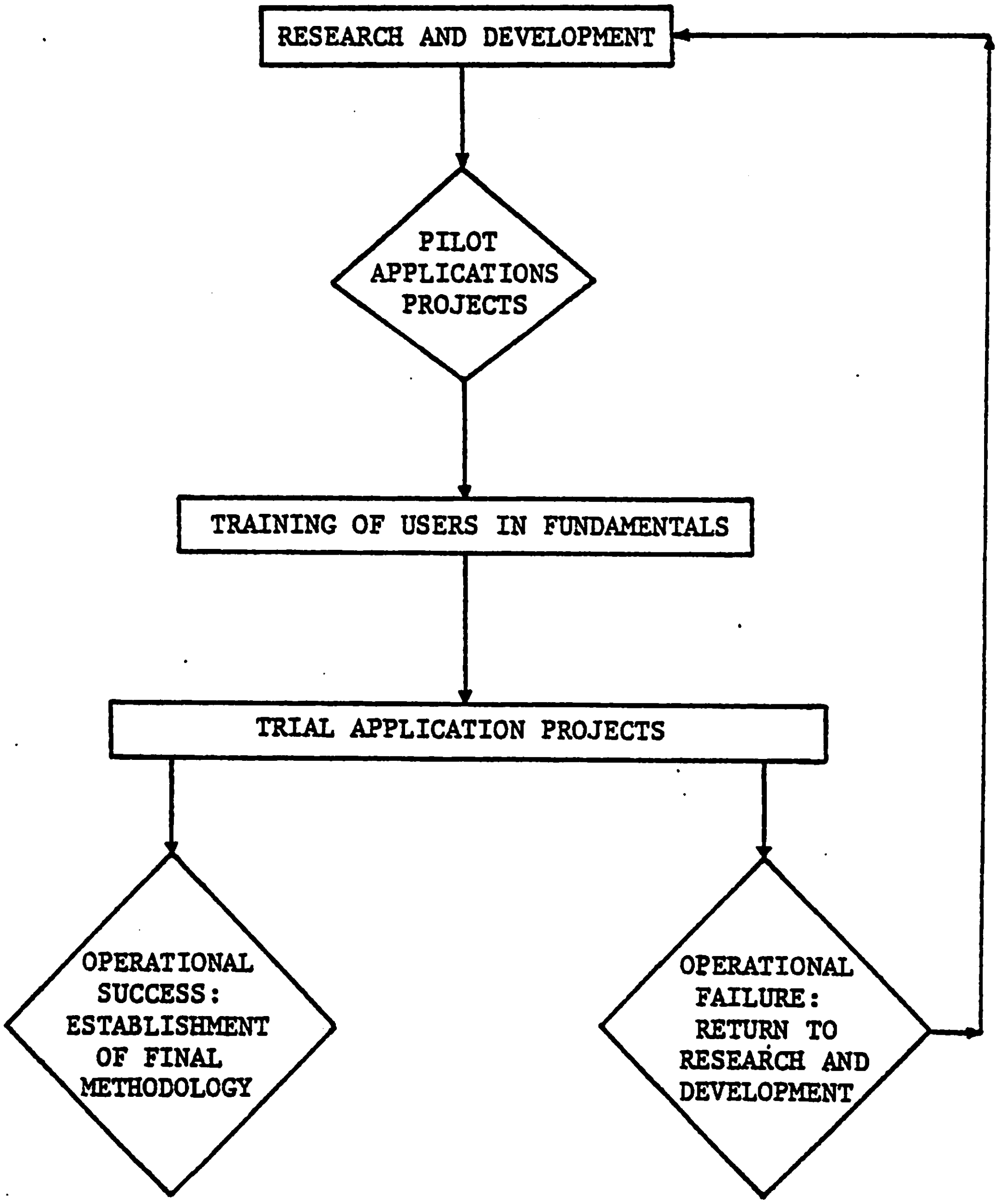


Fig. 1. Flow chart for remote sensing technology transfer.

CONCLUSIONS

Seven years have passed since the application of LANDSAT data to forest fire control operations was initiated and it will be another year before fire control field managers can apply the knowledge they have gained from their training. If the sequence suggested in this paper had been followed and the users had been trained approximately three years ago, the methodology might now be incorporated into operational practice.

It is imperative that any technology transfer program include a training program for potential users so that they will understand the technique and consequently be able to apply it.

LITERATURE CITED

Kourtz, P.H. and Scott, A.J. 1978. An improved image enhancement technique and its application to forest fire management. p. 72-78 *in* Proc. Fifth Can. Symp. on Remote Sensing, Victoria, B.C.

Taylor, M.M. 1972. Perceptual principles related to remote sensing. p. 497-503 *in* Proc. First Can. Symp. on Remote Sensing, Ottawa, Ont. Vol. 2.

Taylor, M.M. 1974. Principal components colour display of ERTS imagery. p. 295-313 in Proc. Second Can. Symp. on Remote Sensing, Guelph, Ont. Vol. 1.

BIOPHYSICAL CLASSIFICATION OF THE HUDSON BAY/JAMES BAY LOWLANDS

S. Pala
Supervisor, Research and Training

A. Boissonneau
Research Officer, Forestry

Ontario Centre for Remote Sensing
Ontario Ministry of Natural Resources
Toronto, Ontario

A methodology for thematic mapping is demonstrated in a project undertaken to map the biophysical/ecological features of the Ontario portion of the Hudson Bay/James Bay Lowlands. LANDSAT imagery, supplemented by aerial photography and selective ground study, was used as the primary data source. Preliminary interpretation, preparations for field sampling, field operations, and mapping procedures are described.

Une méthodologie de cartographie thématique est ici démontrée dans un projet entrepris pour cartographier les caractéristiques biophysiques/écologiques de la partie ontarienne des basses terres de la Baie d'Hudson/Baie James. Les images LANDSAT appuyées de la photographie aérienne et d'études sélectives sur le terrain furent utilisées comme source de données primaires. L'interprétation préliminaire, les préparations pour échantillonnage sur place, les opérations sur le terrain et les méthodes de cartographie sont décrites.

INTRODUCTION

Thematic mapping provides a description, at a predetermined level of detail, for a given feature or condition within a given area. It also supplies a data base upon which more detailed work programs on the mapped theme and related themes may be constructed.

NOTE: Apart from the map (Fig. 1), no illustrations are included in this paper as they would be meaningful only in color. Anyone interested in obtaining color prints of the transparencies shown at the symposium may contact the authors.

This paper describes the methodology used in performing the first comprehensive mapping of the biophysical/ecological units of the Ontario portion of the Hudson Bay/James Bay Lowlands, an area which extends over 250 000 km^2 and is considered to be one of the world's most interesting wetlands. The objective of this program is to provide a level of detail in mapping, and a description of wetland ecosystems, that will be useful in wildlife management, land use planning, and assessment of the environmental impact of developments in northern Ontario.

It would be difficult to produce biophysical classification maps detailed enough to be used without supplementary data. However, today's space technology provides not only high-resolution, high-quality, multitemporal, multi-spectral data for the entire Lowlands area but also the instrumentation to analyze and classify the data. These resources, which have become available to scientists only in this decade, make it possible to produce a broad classification framework in a relatively short time. They also provide an economical means of conducting more detailed studies and integrating the results of those studies into the original framework.

Although satellite data are sufficiently detailed for thematic mapping at a practical scale, some of the finer detail is sacrificed in the process of map production. Therefore, the minimum objectives of the biophysical mapping project are as follows:

1. To provide a synoptic overview of the general ecosystem patterns of the entire Lowlands region so that it will be possible to distinguish areas of significantly different value to wildlife and areas which respond differently to development.

2. To produce detailed descriptions of wetland ecosystem patterns which can be used as a framework for planning more intensive levels of study in small segments of the region.

The project plan was described on several occasions before field work began (Boissonneau 1976, Boissonneau and Pala 1978, Pala 1978). This paper outlines the procedures used and the progress made since the project got under way in 1978.

THE PROJECT TEAM

The biophysical classification of a large and complex area requires input from scientists representing many disciplines. The researchers involved in the mapping project, together with their responsibilities, are listed on the following page.

Simsek Pala, geomorphologist, Ontario Centre for Remote Sensing, organized the field operation, determined representative landing sites using satellite data and aerial photographs, established the correlation between reflectance values on LANDSAT data and site conditions, and established the geomorphological and physiographic characteristics of each site.

Arthur Boissonneau, forester and wetlands specialist, Ontario Centre for Remote Sensing, determined representative landing sites using satellite data and aerial photographs, determined the biological aspects of the biophysical classification, obtained measurements of peat depth and peat samples, and established the dominant vegetation species.

John Riley, botanist, Royal Ontario Museum, obtained, identified and catalogued botanical specimens, obtained measurements of the pH value of the wetland waters, and determined the biological aspects of the biophysical classification.

Andrew Cooper (first field season), *Edward Sado* (second field season), geologists, Ontario Geological Survey, and *Richard Mussakowski*, geologist, Ontario Centre for Remote Sensing, provided information on the general geological characteristics of the area and took samples of surficial deposits for stratigraphic analysis.

John Narraway, Senior Remote Sensing Technician, Ontario Centre for Remote Sensing, estimated the commmercial value of forest stands, monitored wildlife, obtained measurements of peat depth and peat samples, and was in charge of logistics and supply.

DATA SOURCES

LANDSAT imagery was the primary data source for this program. It was essential for developing an understanding of ecosystem and physiographic patterns of the Lowlands, for selecting sampling and fuel cache sites, and for navigating between selected sites, and it will continue to be an important tool during the analysis and mapping stages of the program. Aerial photographs of the region obtained by the federal government in 1953 at a scale of 1:60 000 were used in conjunction with the LANDSAT data to pinpoint the landing sites selected from the satellite imagery.

INSTRUMENTATION

The following equipment was used for field work:

- a four/five-seat helicopter on floats
- 35 mm Nikon cameras for ground photography

- a 70 mm Vinten camera with 150 mm lens mounted in the helicopter for an aerial synopsis
- an auger designed by the Ontario Centre for Remote Sensing and a power drill for peat depth measurements and peat sampling.

The following instruments were used to analyze LANDSAT data during preparation of the classification maps:

- an electro-optical system (ISI System 150 with analogue image storage disk)
- a digital system (NORPAK RGP 3050 with PDP 11/34 computer).

PREPARATIONS FOR FIELD WORK

The first step in preparing for field work was to identify and select sampling sites within each area on the 1:250 000-scale topographic maps. It was important that this be done prior to the field season to ensure that these sites were representative of overall patterns of site variation.

In selecting the sampling sites we studied the satellite data, distinguishing the major types of wetland features, and choosing sample sites representative of each major type and of all the sectors within the type, so that we could determine the homogeneity of the features and map the subtypes. We then examined aerial photographs of the sampling sites and pinpointed the landing sites. We considered 50-60 sites as sampling areas but reduced this number as the homogeneity of wetlands in certain areas became apparent during the field operation. We visited as many sites as possible because we felt that, even if time did not permit a landing at each, or if it became clear that some sites were identical to sites sampled earlier, the aerial photographs we took would be an adequate record of the characteristics of sites not visited.

The second essential task prior to field work consisted of determining helicopter fuel requirements and establishing fuel cache sites. We calculated the anticipated fuel consumption, bearing in mind that although the helicopter could fly approximately 2 hours on one tank, the frequency of takeoffs and landings would require more fuel. To take advantage of good weather and daylight during the short summer in northern Ontario, we arranged for strategic fuel deposits throughout the mapping area. Fuel was flown to selected locations by fixed-wing aircraft and distributed to caches by a large helicopter capable of carrying six barrels at a time. Weather in the study area is subject to abrupt, unpredictable changes, so it was essential to devote as much time as possible to field sampling. All fuel was therefore distributed to the selected cache locations at least one month before field work was begun and only empty fuel barrels were collected and returned to base camp during the field season. This procedure took about three hours each day, either very early in the morning or in the evening. If additional fuel was needed at specific sites during the field operation, the small helicopter was used.

Figure 1 shows all the base camps, fuel caches and ground study sites used in this operation.

FIELD OPERATIONS

Each day it was necessary to finalize the strategy for field operations by taking into account weather conditions, the importance of certain sample sites, and fuel restraints. Navigation in the remote Lowlands would have been difficult for the pilot of a low-flying helicopter if he were using existing topographic maps as these do not distinguish between wetland types. An overview from the helicopter at a higher altitude would have been helpful but it would have been inefficient to change altitudes repeatedly. Satellite imagery, however, was an excellent navigational aid, as it permitted bogs, fens, swamps and marshes to be distinguished from one another.

At each landing site, botanical specimens were collected, depth of peat and pH value of water were measured, dominant vegetation species were identified, morphological characteristics were recorded, ground photographs were taken, and the locations where photographs were taken and what they depicted were recorded. Aerial color coverage was also obtained, using a 70 mm Vinten camera with a 150 mm lens. The camera was mounted on the footrest between the navigator's feet, with the lens protruding through the plexiglass bubble of the helicopter. Sites preselected from the satellite imagery and interesting features observed in the course of the work were photographed to permit a more thorough examination after the field season.

Ten to 15 sites were visited every day, and approximately half an hour was spent at each. It was only by capitalizing on every hour of sunlight that the work was completed according to plan. Occasionally, even when the weather was favorable, dense fog would roll in, and a half day of field work was lost.

Members of the project team used pocket-sized tape recorders to compile field notes because their hands became wet from sampling water, peat and wetland vegetation and recording was therefore much more convenient than writing. Use of recorders also ensured that comments were made immediately rather than delayed and possibly forgotten.

Each evening all the botanical specimens were catalogued and dried, and the strategy of the following day's field work was planned.

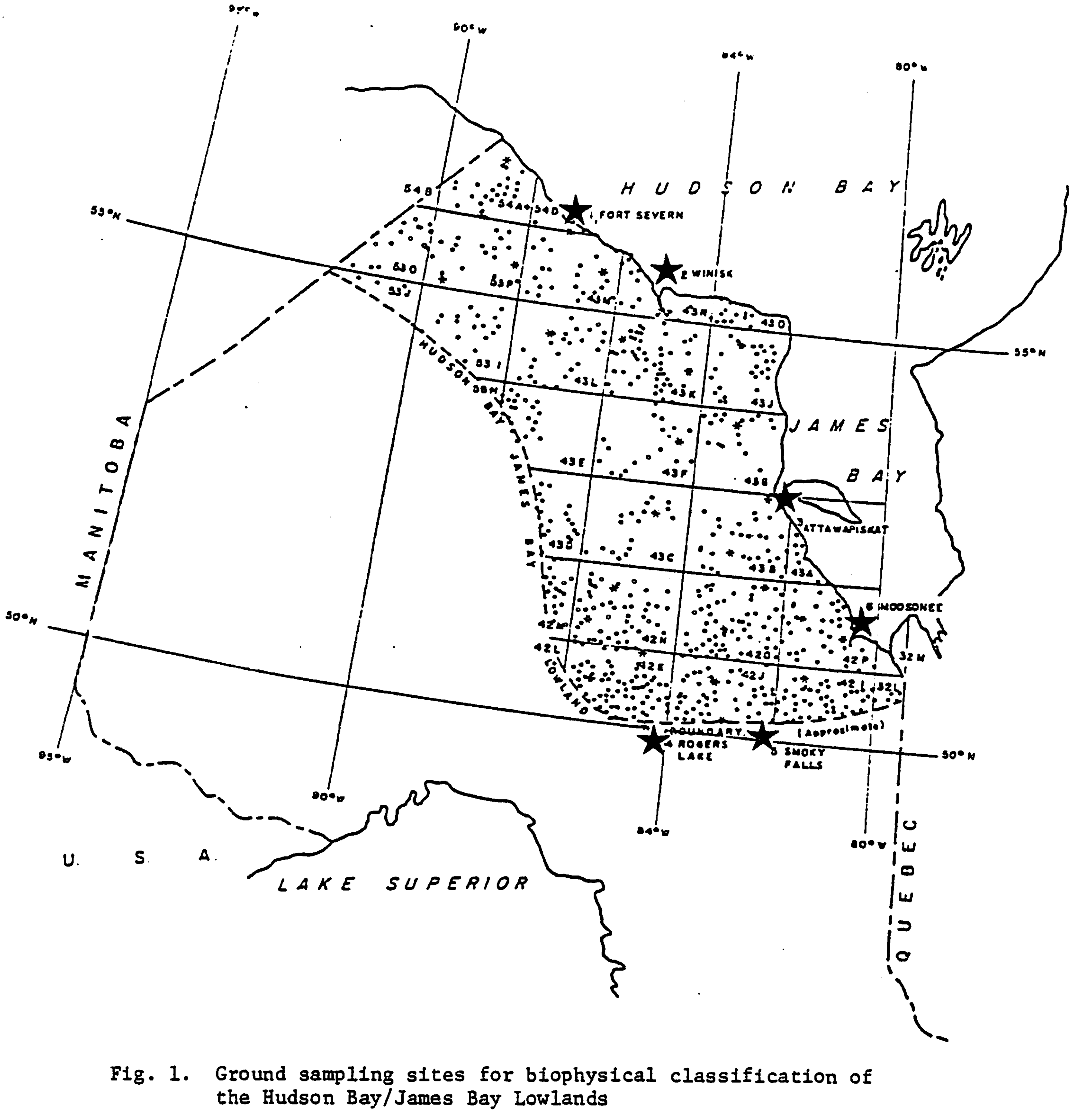


Fig. 1. Ground sampling sites for biophysical classification of the Hudson Bay/James Bay Lowlands

★ Base camp

* Fuel cache

. Ground sampling site

Following the field season the notes were transcribed from tapes and photographs, and botanical specimens and soil samples for each landing site were assembled.

METHODOLOGY OF WETLAND CLASSIFICATION

The Hudson Bay/James Bay Lowlands extend from latitude 50°N to latitude 57°N and range through permafrost-free, discontinuous permafrost and continuous permafrost zones. The same wetland types occur in all three zones, as is evidenced by the same vegetation complexes and processes of development, but they are physiographically altered by the presence or absence of permafrost. For example, a feature that is classified as a bog in the permafrost-free zone will have small ice-cored hummocks and ridges where the permafrost is discontinuous and will become a peat plateau in the continuous permafrost zone. It would be extremely difficult to use analogue or digital electronic analysis for locating different wetland features over more than one zone because reflectance characteristics do not change significantly with the variations in the vegetation cover produced by physiographic changes. Visual interpretation, however, can discriminate between wetland types across the entire Lowlands region. Therefore, it is necessary to compare the electronic analysis with visual interpretation and field records so as to be able to decide whether the class criteria of an already established class should be broadened to include an apparently different feature, or whether a distinct new class should be created. Therefore, the authors plan to use electronic techniques only to analyze small, relatively homogeneous segments of the area so as to provide examples of the level of detail that can be obtained from LANDSAT. Electronic analysis could also be used to compute the area coverage of each distinct wetland type should this information be required in decision-making. The final maps will be the result of a thematic interpretation of data obtained from all three types of analysis (analogue, digital and visual) and will incorporate data collected in the field. To date the project members have assessed the wetland classes used and have established the final mapping classification framework. Among the major units of the Lowlands are the very extensive old beach deposits composed of sand and gravel. These are the only solid ground in the entire Lowlands region apart from the river banks, which are extremely unstable. Maps of the beach deposits were completed in 1978.

Before completing the classification, the authors plan to establish contact with regional biologists and land use planners of the Ontario Ministry of Natural Resources to discuss classification themes so that the information produced can be used in wildlife management, northern development and environmental protection.

The biophysical classification maps will be ready for publication by the end of 1982. The Ontario Geological Survey has generously offered to arrange and fund their publication. Although the maps are being produced at a scale of 1:250 000, they will be photographically reduced, with no loss of detail, to a scale of 1:500 000 for publication. A report describing the results of field work and the samples gathered will accompany the maps.

LITERATURE CITED

Boissonneau, A. 1976. Research and surveys for biophysical mapping in Ontario. p. 33-37 *in* Proc. First Meet. of Can. Comm. Ecol. (Biophys.) Land Classif., Petawawa, Ont.

Boissonneau, A. and Pala, S. 1978. An ecological classification project for the Ontario portion of the Hudson Bay/James Bay Region. p. 65-71 *in* Proc. Can. Comm. Ecol. (Biophys.) Land Classif., Victoria, B.C.

Pala, S. 1978. Spaceborne remotely-sensed data as applied by the Ontario Centre for Remote Sensing: present and future. p. 858-874 *in* Proc. ISP and IUFRO Symp., Freiburg, Germany.

SESSION III

Forest Inventory and Data Base

Chairman: U. Nielsen
Dendron Resource Surveys Ltd.
Ottawa, Ontario

FOREST INVENTORY BY MULTISTAGE REMOTE SENSING

A.H. Aldred
Dendron Resource Surveys Ltd.
Ottawa, Ontario

Several successfully applied forest inventory sampling designs which take advantage of remote sensing data are described. They are then reviewed with respect to the kind of data provided by remote sensing technology and to their efficiency and applicability under different conditions. A progression is followed from simple random sampling through to the more complex multistage designs which combine data from satellite, airborne and ground sources.

L'auteur décrit plusieurs desseins échantillonnage d'inventaires forestiers appliqués avec succès et mettant à profit des données de télédétection. Il les passe ensuite en revue en tenant compte de la sorte de données fournies par la technologie de la télédétection, puis leur efficacité et leur application sous diverses conditions. Il suit un cheminement à partir d'un simple échantillonnage au hasard jusqu'aux dispositifs multiphases plus complexes combinant les données transmises par satellite, celles aéroportées et celles recueillies au sol.

INTRODUCTION

Forest inventory, the collection and presentation of information on the forest for utilization or management purposes, usually has two main phases: 1) production of maps showing location of resource, distribution of forest classes and their relationship to natural and man-made planimetric features, and 2) sampling for detailed information on species, age, size and condition of trees at selected sites in forest stands. Remote sensing (i.e., the collection of all relevant data from either space or airborne sensors, especially by means of aerial photography) has an important role to play in both inventory phases. The role of LANDSAT in mapping will be treated elsewhere in the symposium. Aerial photographs of scales 1:10 000 to 1:50 000 or smaller also play a very important role in forest mapping in all Canadian provinces and the Territories; the procedures are relatively well known and have been summarized by Smith (1975) and by Madill and

Aldred (1977). This paper treats only the sampling phase and attempts to summarize the role of remote sensing in improving the efficiency of sampling. The review begins with some of the simpler approaches that make use of remote sensing data and gradually leads up to the more complex designs, such as classical multistage sampling, which combine space, airborne and ground sources of data. Application of the designs was illustrated by means of slides during the presentation; only the multistage design is illustrated in this paper.

ROLE OF REMOTE SENSING IN FOREST SAMPLING

Sampling is a statistical procedure consisting of the following main steps: 1) identification of target population and characteristics (parameters) to be estimated, 2) definition of sampling units covering the population, 3) selection of sampling units, 4) measurement of selected sampling units, and 5) use of a valid computational procedure to obtain required estimates and measures of their accuracy. The main objective in sampling design is to devise means of obtaining the required estimates more efficiently. The role of remote sensing in improving efficiency can be looked at in two ways. The information from remote sensing sources combined with ground data can be used for estimating quantities of interest (e.g., wood volume or mass) either more accurately for a given level of effort or cost, or else more cheaply to a specified level of accuracy. Of course, it could be that remote sensing provides data that cannot be obtained on the ground. So far, from the sampling standpoint, this has not often been the case in forest inventory. Its substantial contribution to the more efficient sampling of forest data, however, cannot be questioned. Let us look at some of the approaches.

STRATIFIED SAMPLING

Before the advent of aerial photography, forest sampling relied on ground methods based on the examination and measurement of trees along systematically arranged transects (Madill and Aldred 1977). Strip cruising later gave way to random selection of plots or point samples, or clusters of either of these, to improve efficiency and the statistical validity of the estimates. When cheaper sources of information, such as aerial photographs, became available, further improvements in efficiency could be realized. For example, when air photos were used to make forest type maps, the map information could be exploited to divide the forested area into subpopulations or strata. Because of the greater uniformity of volume or other characteristics of interest within these subpopulations, substantial gains in accuracy could be realized at little extra cost. The additional expenditure was small because the forest maps used to produce the strata already existed. All that was necessary was to group the sample units by the strata within which they fell and to find the area of the strata. Sampling within the strata could be treated as simple random sampling.

Stratified random sampling is most efficient when there is a close relationship between the variables used to form the strata and the main characteristic being estimated. Accordingly, variables measured on larger scales of photography are likely to be better correlated to wood volume, for example, than are variables measured or interpreted at smaller scales. Of course, the large scale photo coverage is usually more costly. Likewise, satellite data are likely to be even more vaguely related to the main variable but are still cheaper. Thus, there is a delicate balance of accuracy and cost in considerations of how best to use remote sensing data. The balancing is done with optimization procedures that are only mentioned here. From a practical standpoint, the decision very often depends on what data are currently available and are therefore likely to be cheap and easy to obtain.

A paper by Bickford (1961) provides a more detailed account of stratified random sampling and how to apply it. Freese (1962) also covers the statistical aspects simply and clearly.

REGRESSION SAMPLING

Regression sampling makes fuller use of the quantitative relationship between what may be measured or estimated on the aerial photograph (or other sources of remote sensing data) and the main characteristic of interest which would be measured on the ground. For example, plots can be established on aerial photographs and interpreted, and species composition, crown cover density and stand height assessments can be used in aerial stand volume tables or equations to estimate wood volume (Bonnor 1975). The same information can be measured on the ground but at a much higher cost. The double sampling for regression design, also called multiphase sampling, makes use of a large number of cheap photo plots and the remeasurement of a few of these photo plots on the ground. A linear regression between the ground measured volume (Y) and photo volume (X) is found by using standard simple linear regression procedures, and is applied subsequently to the large number of photo plots not measured on the ground. In effect, the regression is used to calibrate the photo estimates to increase accuracy and minimize bias. Optimization equations are used to find the relative number of photo and ground plots. The closeness of the regression relationship and relative costs are the main variables used to find the optimum ratio. Medium-scale photos use stand characteristics to provide relatively crude estimates of volume; large-scale photos on which individual trees are assessed and measured provide estimates of volume, for example, that are nearly as accurate as ground measurements themselves (Aldred and Lowe 1978, Nielsen et al. 1979). The optimization formula will be affected by both the closer relationship and the higher cost of the photo measurement work at the larger scales.

CLUSTER SAMPLING

In cluster sampling the sample plots are grouped together in close association. Ground plots grouped along a transect in a block (Fig. 1) or in some other pattern such as a cross are examples of clusters. The advantage of clustering is that the close association reduces travel time and may mean a more productive use of field staff. A cluster could just as well be a series of photo plots along a strip; in this case it is considerably easier (and therefore more efficient) to fly along a line rather than, for example, to scattered random locations.

In cluster sampling, the target population is completely covered with clusters, a few of which are selected for sampling. These could be blocks or strips which are aggregates of some smaller unit such as plots. After a few clusters are selected, a second sample of the secondary units (plots) is drawn from the clusters and measured for the required characteristics. In the case of large-scale photography, the strips of photos would be the clusters, and selected stereo pairs on which plots are established and measured would be the secondary sample. Cluster sampling is also used in standard ground plot sampling. In fact, the sample plot itself can be regarded as a cluster sample, the trees themselves being the secondary elements.

MULTISTAGE SAMPLING

Classical multistage sampling is a special type of cluster sampling. First, the population of interest is divided into primary sampling units which could be equivalent to the strips of photos referred to under cluster sampling or to contiguous blocks covering the population. Each block is then assessed in terms of some quantity related to the characteristic of interest. For example, suppose that an estimate of total coniferous volume of a given area is required, that the entire area has been covered by LANDSAT and that a grid of perhaps 10 km cells has been superimposed on the area (Fig. 1). The satellite information could then be used to estimate the proportion of a cell occupied by coniferous forest. A sample of primary units (blocks) with a probability proportional to the coniferous volume found on the cells would be selected. These primary sampling units would then be subdivided into smaller units called secondary sampling units (Fig. 1). In the example, cells could be divided into a series of strips covering the block. Each strip would be assessed again in terms of variables related to volume. For instance, existing small- or medium-scale photography could be used, in conjunction with aerial stand volume tables based on species composition, crown cover density and average stand height, to estimate stand volume.

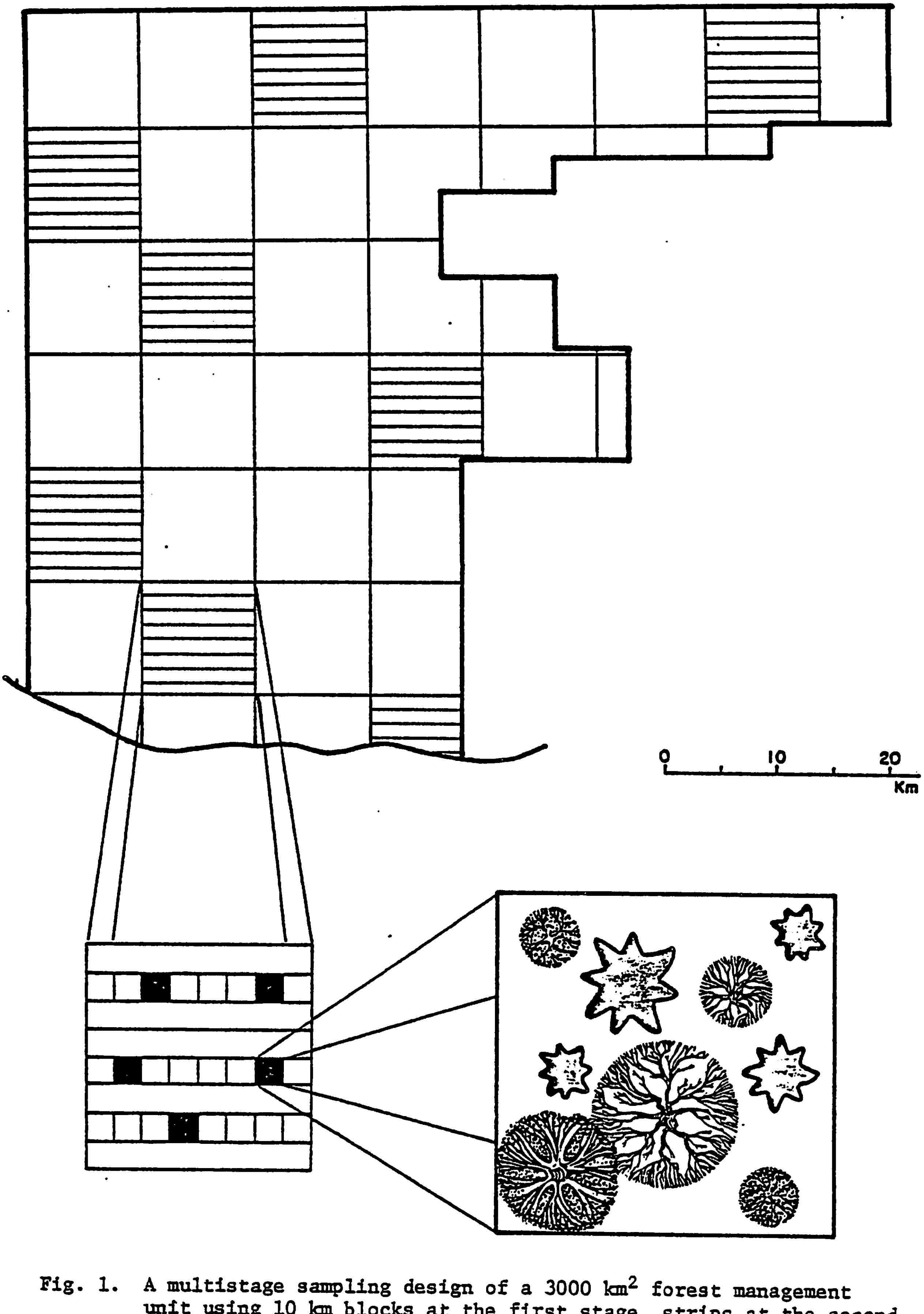


Fig. 1. A multistage sampling design of a 3000 km^2 forest management unit using 10 km blocks at the first stage, strips at the second stage, plots at the third stage and trees at the fourth stage.

Such estimates could be accumulated along the strips to produce strip estimates of coniferous volume. These estimates would be used in a probability-proportional-to-estimated-volume framework to select a few strips for further sampling. The selected strips could then be divided into tertiary sampling units as shown in Figure 1. In the example, the selected strips would be flown at low altitude, where the large-scale photo plots along the strip would correspond to the tertiary units. The large-scale photo plots would be measured on an individual tree basis to obtain accurate estimates of plot volume. The fourth and final stage would be the selection of some photo plots with probability proportional to large-scale photo plot volume. The photo-estimated tree volume on these plots would be used to select, with probability proportional to coniferous tree volume, a few trees (the quaternary sampling unit) for detailed ground measurement, perhaps dendrometer measurement or felling and sectioning. The final, accurate tree measurements would then be projected through the network of probabilities occurring at each stage to produce an average volume per hectare or total volume along with an accompanying accuracy estimate. The multistage design, including development of statistics, is described in detail by Langley (1969); a recent application by Kirby and van Eck (1977) in Alberta uses a similar approach.

HYBRID DESIGNS

Many combinations of the preceding sampling approaches have the advantage of specific adaptation to particular problems but at the cost, frequently, of complicated statistical derivation and computation. Two successfully applied hybrids which use remote sensing data are described in the following paragraphs.

The two-stage cluster sampling design discussed by Bonnor (1975) was specially developed for large-scale sampling photos. In this design the population is first divided into strata on the basis of aggregations of forest stand types used in forest mapping. The aggregations are based on volume or commercial forest categories. A grid of evenly spaced transects is laid across the various strata. Some of these are selected for large-scale photography, with probability proportional to the length of the transect. The selected transects are flown at low altitude and stereo pairs of photos are then selected from the strip at random. Detailed tree measurements on photo plots are used to produce accurate plot volume estimates, a few of which may be remeasured on the ground for calibration and checking purposes. The plot estimates are then compiled to produce stratum estimates of mean and total volume. The stratum estimates can be used to compile population values and accompanying accuracy estimates. This design takes advantage of existing information on forest cover types and the efficiency of photo sampling along transects. The design has been used in two operational trials of large-scale photography for forest inventory purposes (Aldred and Lowe 1978, Nielsen et al. 1979).

A new design recently described by W.R. Dempster (pers. comm. 1979) combines probability proportional to size (PPS) sampling at the first two stages with double sampling for regression (large-scale photo/ground) to obtain detailed estimates of coniferous volume at the last stage. The primary sampling units used are township blocks (about 93 km^2) covering the target area. Preliminary estimates of volume by block are obtained from aerial stand volume tables applied to stand variables estimated on 1:50 000 color infrared photos. The first stage sample is drawn with probability proportional to estimated volume. Each selected block is divided into strips (the secondary sampling units) using stand volume estimates as in the multistage design. The strips (clusters) for large-scale photography are selected with probability proportional to estimated strip volume. At this stage a random sample of large-scale photo plots is drawn from the strips of photography and a more accurate estimate of stand volume is made using plot area, crown area by species, stand height and stem count. A subsample of photo plots is drawn and the plots are remeasured on the ground. The large sample of photo plots and the small sample of ground plots are used in a double sampling regression framework to obtain corrected photo plot estimates. These are projected back through the probabilities in the first two stages to determine the required estimates of population volume.

The preceding design and others like it which use stratification, regression or simple random sampling at some stage are not technically multistage designs. A multistage design, whether of two, three or more stages, can be recognized by the redefinition of clusters at each lower stage and the use of PPS selection criteria within each stage.

CONCLUSIONS

Generally speaking, the simpler sampling designs such as simple random sampling are the least efficient for specific applications but are easier to understand and apply correctly and are more flexible where several applications of the sampled data are involved. For example, the stratified random sampling design can be used for any kind or level of stratification if it is designed correctly. This is particularly helpful where the strata change with time and redefinition of strata occur periodically.

The multistage designs, on the other hand, are well suited to large, regional forest inventories but they lack estimates for many of the subdivisions (e.g., primary sampling units which are not subsequently sampled). Likewise, stratification, such as that from cover type mapping, tends to interfere with the efficiency of the classical multistage approach. The stratification, regression and cluster designs frequently work best for the more detailed inventories because they can make use of existing (and therefore inexpensive) information and permit estimates to be made of subdivisions in the population. The regression estimates, however, require close attention to assumptions underlying linear regression. Violations of these assumptions can lead to biased estimates. The cluster designs have to be analyzed carefully to ensure that they in fact will produce the results more efficiently than simpler designs. The stratified sampling designs are much more forgiving with respect to statistical assumptions, are much easier to apply, yet still take advantage of information from photos and other sources of remote sensing data.

Each forest inventory job should be studied carefully beforehand with these considerations in mind to ensure that the data requirements will be fulfilled and that the best use will be made of several possible sources of remote sensing data.

LITERATURE CITED

Aldred, A.H. and Lowe, J.J. 1978. Application of large-scale photos to a forest inventory in Alberta. Dep. Environ., Can. For. Serv., Ottawa, Ont. Inf. Rep. FMR-X-107. 57 p.

Bickford, C.A. 1961. Stratification for timber cruising. J. For. 59(10):761-763.

Bonnor, G.M. 1975. Cluster sampling with large-scale aerial photography in forest inventories. Dep. Environ., Can. For. Serv., Ottawa, Ont. Inf. Rep. FMR-X-80. 26 p.

Freese, F. 1962. Elementary forest sampling. USDA Agric. Handb. No. 232. 78 p.

Kirby, C.L. and Van Eck, P.I. 1977. A basis for multistage forest inventory in the boreal forest region. p. 71-94 *in* Proc. Can. Symp. on Remote Sensing, Quebec, Que.

Langley, R.G. 1969. New multi-stage sampling technique using space and aircraft imagery for forest inventory. p. 1179-1192 *in* Proc. Sixth Internatl. Symp. on Remote Sensing of the Environ., Ann Arbor, Mich.

Madill, R.J. and Aldred, A.H. 1977. Forest resource mapping in Canada. Can. Surveyor 31(1):9-20.

Nielsen, U., Aldred, A.H. and MacLeod, D.A. 1979. A forest inventory in the Yukon using large-scale photo sampling techniques. Dep. Environ., Can. For. Serv., Ottawa, Ont. Inf. Rep. FMR-X-121. 40 p.

Smith, V.G. 1975. An overview of Canadian inventory methods. Proc. of CIF Working Groups on For. Invent. Remote Sensing and Biometr., Dorset, Ont. 283 p.

Discussion

It was speculated that estimation of stand volume might be best undertaken using photography at the tertiary level of sampling in multistage remote sensing. The speaker agreed that, depending upon such factors as access, remoteness, and relative cost, volume estimation using aerial photography could be preferable to ground sampling.

TREE MEASUREMENT FROM LARGE-SCALE PHOTOGRAPHY

A. Jano, Environmental Specialist
Ontario Centre for Remote Sensing
Ontario Ministry of Natural Resources
Toronto, Ontario

J.A. Mervart, Mensurationist
Timber Sales Branch
Ontario Ministry of Natural Resources
Toronto, Ontario

A method for measuring and estimating tree and stand parameters from aerial photographs is described. Results of tests regarding measurement accuracy are analyzed. Limitations of the method as an operational survey technique are discussed. Recommendations are made concerning equipment and further research.

Ce document décrit une méthode pour mesurer et évaluer les paramètres des arbres et des peuplements à partir de photographies aériennes. Les résultats des tests relatifs à la précision du mesurage sont analysés. Suit une discussion sur les restrictions de la méthode employée en tant que technique de relevé opérationnelle. Enfin des recommandations sont faites quant a l'équipement et à la poursuite des recherches.

INTRODUCTION

Since 1975, the Ontario Centre for Remote Sensing (OCRS) in cooperation with the Timber Sales Branch of the Ontario Ministry of Natural Resources (OMNR), has been involved in the development of a large-scale aerial photo sampling method, known as aerial cruising, that would replace most or all inventory ground data with photogrammetric measurements.

As an introduction to the scope and problems of aerial cruising in the Ontario Ministry of Natural Resources, a few words about Ontario forest management planning and inventories might be in order.

There are two kinds of forest inventory in use: the forest resource inventory (FRI) and the operational survey. The purpose of the FRI is to provide a framework for long-term planning, for determination of the allowable cut by area and for a preliminary allocation of cut to individual stands. FRI data are acquired by photointerpretation and are geared primarily to land *area* classification and description.

Timber volume information for individual stands is of secondary importance to the FRI. It is derived by applying standard yield tables to stand parameters estimated from the photos. The volume data thus obtained are only rough estimates, and need not be anything more than that. The cut is controlled on the basis of area/age class; stands selected as possible candidates for cutting will be surveyed in detail later by an operational survey.

The operational survey is conducted to determine on the ground whether or not the stands preselected for cutting are operable from the silvicultural as well as the logging point of view and, for those which are confirmed for cutting, to determine their *volume by species and DBH classes*. Sometimes it is conducted to classify stands by quality, grade or product as well. Traditionally, the volume figures are determined in operational surveys through ground sampling of each stand.

Ground sampling for timber volume is a laborious and costly operation, particularly in areas which are not easily accessible. The Ministry was interested, therefore, in exploring the capability of remote sensing techniques to complement, or possibly replace, operational cruising on the ground.

Research began in 1975. The methodology adopted was that chosen by the Forest Management Institute (FMI)—the estimation of DBH or volume via regression on tree parameters which can be measured on aerial photos. However, the basic requirements which the aerial cruise must satisfy are substantially different from those of inventories so far undertaken by this method. As an operational survey technique, the aerial cruise is required to provide volume estimates of a relatively high accuracy; moreover, the estimates must be made according to individual species and relatively narrow DBH classes. However, the most demanding requirement of the aerial cruise is that it provide volume estimates by individual stands.

Stands range in area from a few hectares to perhaps a hundred, and therefore represent very small inventory units. The choice of the stand as the inventory unit practically precludes the use of a more efficient sampling design, but above all, it necessitates the acquisition of a specific regression estimator for each and every stand to be inventoried.

If each stand had to be visited and pre-sampled to decide its specific regression estimator, there would be no point in the new method: it would be less costly simply to cruise the stand in the ordinary fashion. Therefore, in the context of the Ontario Inventory System, the aerial cruise would never be operationally justified unless the need for pre-sampling each stand on the ground could be obviated.

Deriving the regression estimators solely from measurements on photos (i.e., by an optical tally of DBH and height) may be technically feasible, but it does not offer acceptable accuracy. The main problem is that softwood stems are usually hidden by the canopy. Therefore, collecting regression data on trees with exposed stems would involve the risk of heavily biased estimators, since the regression would be based on observations of solitary trees and trees growing in patches of low stocking.

This problem led to a consideration of how specific regression estimators are to individual species and to individual stands of the same species. Would it be possible to use a regression estimator derived for one stand in another stand as well--at least in the same general area? And if the regression parameters were distinctly site-specific, was there any association between the parameters of the estimator and stand characteristics measurable on the photos so that the estimator could be predicted without resorting to ground sampling of each stand?

In the light of these questions, the test was restricted, for the time being, to the simple model

$$\widehat{DBH} \text{ (or volume)} = B_0 + B_1 \, HT\sqrt{CA}$$

where: HT is height

CA is crown area

B_0 and B_1 are coefficients

originally proposed by Aldred and Sayn-Wittgenstein (1972), and to testing the method in pure stands.

The other aspect of the test was, of course, how well the aerial technique performed and what problems might be encountered in applying it on a larger scale.

AERIAL CRUISE TECHNIQUE

The aerial cruise technique and the approach employed by OCRS have changed considerably since they were introduced. At first, the ground cruise procedure was followed quite closely. The emphasis was placed on direct photogrammetric measurement of the heights and diameters of deciduous trees on winter photographs. This approach is described in detail by Zsilinszky and Palabekiroglu (1975). Originally, 35 mm cameras were used. Difficulties associated with the small format and small scales were eliminated by a conversion to 70 mm photography. In the course of the first trials, a poplar and a jack pine plot were photographed. Diameters of all trees within the plots were measured on the ground along with a sufficient number of heights for height curve construction. The photogrammetric measurements were carried out on a

Wild A-9 first-order stereo plotter interfaced with a Wild EK-22 digittizer and an IBM 731 typewriter. The system's output was a listing of XYZ coordinates of the principal points of trees. Much manual calculation was needed to produce the required height and diameter data.

The direct diameter measurement approach is limited to pure deciduous stands. To extend the aerial cruise concept to the measurements of conifer stands (pure and mixed), the original approach was abandoned in favor of measuring the heights and crown areas of trees on summer photographs and estimating the diameters (or volumes) from these variables. To handle the large number of points required for crown area measurement, a programmable calculator was added to the plotter. With this addition the measurement process was speeded up considerably because the need for manual calculations was eliminated.

In the past two years, 40 test plots have been photographed, and measured on the ground and on the photographs, in order to evaluate the feasibility of estimating DBH or volume via regression on height and crown area. The test areas were located in pure stands of the most common boreal species.

Panchromatic photographs of short strips transecting preselected stands were taken with a Vinten camera equipped with a 6 in. (15.24 cm) lens. The contact scale of the photography was approximately 1:1 500. To facilitate the locating of strips on the ground, wide-angle coverage was obtained simultaneously.

On the ground, more or less rectangular plots with an average area of 0.1 ha were selected. Points clearly identifiable both on the ground and on the photographs were chosen as corner points. The distances along the plot perimeter were measured and recorded. All trees within the plot were numbered on the ground and identified by number on the photographs. Diameter measurements were taken for all trees, and height measurements for about one-third of the trees. It was therefore possible to compare ground and aerial measurements on a one-to-one basis.

Photogrammetric measurements were carried out on a Wild A-9 stereo plotter. The following measurement procedure was used.

Positive contact transparencies of the stereo pair covering the plot were set up on the plotter. Relative orientation of the stereo model was performed in the usual manner, and was followed by a rough absolute orientation using the more or less vertical trees as a guide. The contact scale of the photographs was determined from photo measurements of the known ground distances between plot corners. The horizontal and vertical model scales were computed from the contact scale and from the appropriate settings of the plotter.

For each tree the identification number was entered; then the coordinates of the tree top and the coordinates of a point at ground level near the tree base were used in height calculation. As the floating mark was moved around the crown, the crown area was computed from the coordinates of points located at desired intervals along the perimeter.

The output of this system is a listing of trees by number along with their height and crown area. The heading of the list contains information on plot identification, scales, altitude, and relevant settings of the plotter.

Results with respect to precision of the aerial cruise and the specificity of the estimators can be summarized as follows:

1. Standard errors around the regressions of ground-measured DBH on aerial $HT\sqrt{CA}$ ranged from 5% to 15% of the mean; an error of about 10% was encountered in most cases.

2. No association could be established between species and relative precision of the estimator. Well structured stands exhibiting a definite gradation of height with increasing DBH seemed to yield more precise estimators. Also, in such stands the inclusion of height within the independent variable was an important contributor to the reduction of the variation around the regression. In some jack pine stands with poor height differentiation, the inclusion of height did not make much difference, as the major contributor was the crown area.

3. Where DBH for a given plot was estimated by means of its regression estimators, the basal areas per hectare were found to be within ±3% of the correct values in most cases. Usually there was a slight distortion, however, in the distribution by diameter classes. The distribution based on estimated DBH was usually more condensed around the mean DBH and this indicated that the smallest trees were shifted into the next higher DBH class. This tendency was especially apparent in stands with a high proportion of trees in lower DBH classes (such as in black spruce). The DBH of individual trees was estimated with a precision of ±4 cm (at a 90% probability level).

4. Volume estimates of the aerial cruise were less reliable. In some instances, the difference between the estimated plot volume and volume based on ground data was a few percent; occasionally, however, it reached 25%. The reason for such differences was that problems were encountered in measuring heights from the photos.

5. Estimation of height appears to be the most vulnerable part of the aerial cruise: height of short trees is overestimated and height of tall trees is underestimated. The magnitude of the discrepancy depends on many factors, including the experience of the interpreter. Data on one set of plots measured independently by two interpreters also showed that there was much less consistency between interpreters in height measurements than in crown area measurements.

6. The problem of distortion of volume estimates because of inaccurately assessed heights could be overcome in part by regressing *volume* (instead of DBH) on height and crown area. This approach was tried on the final set of plots for GTV (gross total volume) estimation. As anticipated, the coefficients of correlations between volume and the $HT\sqrt{CA}$ were usually higher than for DBH. However, the relative standard errors of the volume estimators were twice to four times larger than the relative standard errors of the DBH estimators for the same plots, and with the same interpreter.

   It would seem, therefore, that the regression of volume on height and crown area may not be as efficient as could be expected. In operational surveys, a volume breakdown by DBH classes and/or a stand table, giving stem frequencies by DBH, are required in any case, and in operational conditions, collecting data for the direct volume estimator would be substantially more expensive than collecting data for the DBH estimator.

7. Data from the test plots show that the DBH estimates are species-specific and site-specific. We even encountered a situation in which estimators for adjacent stands of the same species significantly differed in their parameters. The pooling of data and, in particular, extrapolation (i.e., using the estimator devised for one stand in another stand) may lead to serious inaccuracies in the estimates. So far, stand parameters have not been found which would be associated with the regression parameters so closely as to make extrapolation reasonably safe.

8. Comparisons of aerial cruises made for the same plots independently by different interpreters have shown that the interpretation is not free from personal bias. As mentioned before, the most marked differences were in height assessment.

   The data show that the disagreement between interpreters in height assessment could result in extremely inaccurate volume estimates if the estimator was derived from data collected by one person and then applied to the survey area by a different person.

   This may cause practical problems in large-scale applications of the aerial method.

ACCURACY OF THE PHOTO MEASUREMENTS

The results presented in the previous section indicate that the accuracy of height measurements is far from acceptable. There is a general tendency to overestimate heights. A comparison of aerial and ground DBH distributions indicated that, in addition to the general overestimation, small trees were overestimated in relation to tall trees.

A comparison of the height measurements of individual trees taken by two independent operators showed considerably less agreement than similarly produced crown area measurements. In one plot, differences between the two heights were as great as 7 m.

The difficulties encountered in height measurements led to the following conclusions:

Differences between independent measurements of the same trees are partly associated with the measurement procedure: while the tree top is usually well defined, often the tree base is not. A lack of adequate detail at ground level, especially in dense stands, makes the ground level measurement the suspected cause of discrepancies. Significantly, height measurements in dense poplar stands gave the poorest results. In more open jack pine and spruce plots, the correlation between height measurements was much higher.

As for the overestimation of heights and the distortion of height-DBH curves, the problem appears to be related to a lack of tip and tilt control both in the photography and in the measurement procedure.

It is recognized that an acceptable level of accuracy cannot be expected from photographic and photogrammetric equipment available at this time for the following reasons:

1. The small base-to-height ratio of the stereo pairs (approximately 1:12) creates serious difficulties in the relative orientation of the model, and lowers the accuracy of the height measurements.

2. The limited focal length range of the plotter creates a model with different horizontal and vertical scales, the latter being smaller by a factor of at least 1.5, if the photographs are taken with a 6 in. lens. This, in effect, compresses the model in the vertical direction, further decreasing the accuracy of height measurements. Nevertheless, the presence of a tilt error that would result in height errors of such magnitude is difficult to explain.

The cause would appear to be an over-reliance on the optical and mechanical procedure for orienting the stereo pair, in view of the fact that the photographs have been taken using a lens with unknown distortions. Although the Vinten lenses are not of photogrammetric quality, the suspected distortions are probably not large. Nevertheless, parallaxes caused by lens distortion or by tilt could have a similar appearance. An attempt to clear parallaxes caused by lens distortion with the adjustment of Y tilt has a serious effect on height measurement as it distorts the photo base of the model. Because the Y-tilt adjustment is ineffective in clearing Y parallaxes, elimination of a small amount of parallax requires a considerable change in differential tilt.

Two ways of eliminating this source of error are available. The first is to ignore differential tilt on the assumption that it cannot be very great between two exposures taken 1/4 to 1/8 of a second apart. The better and more expensive solution is to acquire the orientation data independently, through the use of a tilt-recording device. The assumed or measured tilt would then be used to orient the stereo model. Unfortunately, both of these approaches would create visual difficulties on any analogue plotter because of the large Y parallaxes left in the model. This, in turn, would make the measurement process impossible or too cumbersome to be practical.

However, either the assumption or measurement of tilt would work well if an analytical instrument were used. The model could be set up correctly, with the presence of Y parallaxes creating no problem, because of the basic operating principle of the instrument.

Regardless of how accurate the measurement of variables for individual plots may be, problems will still be encountered when aerial cruising is used as an operational survey technique. To overcome these difficulties, the aerial cruising method will probably require additional photo-measurable stand information to determine the DBH or volume estimator without resorting to ground sampling. The search for such additional information will begin only after the problems of obtaining accurate photogrammetric measurements have been solved.

Discussion

The question was raised as to whether the difficulty in estimating tree height using large-scale aerial photography could be overcome by improvements in photogrammetry or the use of more experienced interpreters. The former was seen as the larger source of increased accuracy. The point was raised several times that ground measurements of total height cannot be accepted as accurate.

A NEW APPROACH TO FOREST INVENTORY USING REMOTE SENSING

F. Hegyi
Director, Inventory Branch
Ministry of Forests
Province of British Columbia
Victoria, British Columbia

This paper describes a new system, based on remote sensing, that has been developed by the Inventory Branch of the B.C. Ministry of Forests for forest inventory. The system uses a combination of multistage and multiphase sampling. Satellite image analysis is used mainly for updating changes and for optimizing the application of supplementary aerial photography.

Cet article décrit un nouveau système fondé sur la télédétection, qui a été mis sur pied par la Division des Inventaires du ministère des forêts de la C.-B. pour les inventaires forestiers. Le système utilise une combinaison d'échantillonnages à multiphases et à multistages. L'analyse des images satellites est employée surtout pour mettre à jour les modifications et pour optimiser l'application de la photographie aérienne auxiliaire.

INTRODUCTION

The 1978 Forest Act in British Columbia requires that an inventory of the land and forests be developed and maintained and that the land be assessed for its potential for growing trees continuously, providing forest-oriented recreation, producing forage for livestock and wildlife and accommodating other forest uses. In addition, the Minister of Forests is required to submit to the Lieutenant-Governor in Council an annual report which must include a summary of forest land in the province, showing areas denuded and restocked during the year, and the land where productivity was improved.

In order to meet the requirements of the new legislation, the Inventory Branch of the Ministry of Forests has acquired new technology and developed new approaches for conducting forest inventory.

Prior to 1978 the provincial inventory program consisted mainly of unit surveys which were implemented on a 10-year cycle. The classification system used during these surveys stratified the land into broad classes, such as forest, non-forest, species group, site types, age class, height class, stocking class, etc. Since 1973, the management unit inventory program has been expanded to include the identification of environmental protection areas, including the mapping of sensitive areas in terms of soil and steepness problems, regeneration and plantation constraints, inoperability, avalanche and snow chute problems, high recreational values, and essential habitat for wildlife and fish. In 1977, a more detailed level of inventory was developed which generally covers a watershed or a sub-unit. An integral part of the sub-unit inventory system was the development of a new classification and sampling methodology.

CLASSIFICATION AND SAMPLING

The previous inventory program consisted mainly of aerial photo-interpretation on 1:15 840 photographs and ground sampling. Each major forest type group was sampled by clusters of two or four fixed-radius plots and generally up to 16 samples were collected per type group. A major problem with this approach was that often some type groups in remote areas were not sampled and a cluster of two fixed-radius plots did not always represent its stratum.

The new inventory system is also based on aerial photointerpretation, but homogeneous types are being described in more detail and are sampled with the aid of low-level aerial photo plots through double sampling. The system is generally applied to a management unit area, such as a Sustained Yield Unit (SYU) or Timber Supply Area (TSA). Aerial photographs are pre-typed into homogeneous strata prior to the beginning of field sampling. The scale of photography for management unit surveys is 1:20 000, although in some cases the 1:15 000 scale is accepted as a practical alternative. When highly detailed information is required on any particular part of a management unit such as a watershed (sub-unit), aerial photographs at the 1:10 000 scale are most often used. Boundaries of homogeneous strata are transferred to base maps via kail plotting. Each stratum or type is given a unique number both on the maps and on the aerial photographs. During the field season, aerial photo interpreters (classifiers) work closely with the field crews to obtain samples of the various strata. Large-scale (1:200 - 1:1 000) fixed-base aerial photography is also obtained in a representative manner on approximately 10% of the strata, using twin Hasselblad 70 mm cameras mounted a fixed distance apart on an aerial camera platform attached to a helicopter. In most cases, the photo interpreter is in the helicopter when the 70 mm stereo photos are taken and he/she has a tape recorder on which pertinent observations are recorded to aid in subsequent species identification on aerial photographs. Six fixed-radius plots per type or stratum are located on the large-scale aerial photographs and these constitute the primary samples.

Measurements on the photo plots include stem count, height and crown diameter by species and crown closure for the sample. Sub-samples of the primary samples, generally up to 15 per type group, are visited on the ground for detailed measurements; these constitute the secondary sample units. Each secondary sample consists of six point samples, taken approximately at the same place where the primary samples were obtained. Both the primary and secondary samples are located with the main objective of obtaining a representative sample of their host stratum, rather than establishing tree to tree correspondence between them. This modification of multi-phase sampling is mainly for optimization of costs, and is followed by variance--obtaining representative samples per stratum at each stage reduces variance--and then the optimization of correlation, at an acceptable cost, between the auxiliary variables of primary samples and the primary variables of secondary samples.

Measurements on secondary samples include diameter at breast height, age, height and pathological indicators for each tree, as well as species identification and assessment of crown closure. Depending on the objectives of the inventory, special measurements are often obtained on secondary samples, such as information on soil, environmental conditions, etc. While secondary samples consist mainly of six points, located in a straight line across the stratum, where the in-trees are selected with the aid of a relascope, fixed-radius plots are recommended for types in which a large portion of the trees are below the minimum diameter limit. In the case of point samples, the band is selected so that 8 to 12 trees are included in the sample at each point; similarly for fixed-radius plots, the objective is to obtain 50 to 70 trees per sample (in a total of six plots); hence, plot sizes are selected accordingly.

Approximately 20% of the secondary samples are selected, in a representative manner, as tertiary samples for the assessment of growth and depletion. Permanent growth sample plots are established at the even-numbered points, whereas destructive sampling for decay and waste is done at the odd-numbered points.

On the basis of the data obtained from large-scale aerial photographs (primary samples), field sample plots (secondary and tertiary samples) and ground calls, the 1:20 000 aerial photographs are interpreted in terms of the classification system. The description for each stratum is entered into an attribute file and referenced through the unique numbers. The classification system is applied consistently in a horizontal (stratum) and vertical (layers) plane; hence, a separate description is given for each layer of multi-storey stands. The principal variables recognized by the classification and sampling systems are forest, range, non-forest, barren and cultivated land. An especially significant aspect of the new inventory system is the classification of forest land which is now described in terms of species composition, age or date of establishment, height, crown closure, stocking, history, environmental constraints and ecological parameters.

COMPUTERIZED MAPPING

The inventory system described above is being implemented simultaneously in each of the six regions in British Columbia during the summer months. Hence, a large number of maps must be processed in a short period of time to facilitate the calculation of the required area and descriptive statistics. In addition, the remaining forest type maps must also be updated on a yearly basis in terms of such changes as harvesting, regeneration and other relevant depletion. Coinciding with these requirements is the need to manage the data base with a flexible retrieval system and to convert the 7,000+ forest cover maps from the English to the S.I. system, including changes in map sheet sizes from 7'30" by 7'30" (1:15 840 scale) to 12' longitude and 6' latitude (1:20 000 scale).

In order to be able to process the heavy workload within fairly rigid time constraints, the Inventory Branch acquired in 1978 an Interactive Graphics Design System (IGDS) from M & S Computing International Ltd. IGDS is an integrated configuration of hardware and software, featuring user-controlled graphics combined with data management and retrieval systems. The configuration installed at the Inventory Branch includes the following: two PDP 11/70 computer sub-systems operating in a dual-port environment with 256K word memory on each CPU; two 80 and two 300 megabyte disk drives with packs, operating with data scanners; ten design/digitizer stations, each consisting of two Tektronix screens, a Summagraphics digitizing table (approx. 91 x 122 cm) with menu and cursor, and a keyboard; a system console and CRT terminals; a tape drive and controller; a Calcomp 960 plotter, a card reader, printer and two hard copy units; and an interface controller to the IBM 3033 computer. The software acquired with the system facilitates interactive manipulations and editing of graphic elements and designs, interactive and batch input of map labels containing thematic details, automatic area calculations, and data management and retrieval capabilities. IGDS is capable of storing each design file or map in terms of 63 levels, each of which may be retrieved separately or collectively in any combination. Formal overlays of design files can also be created and areas of original and resultant types and their associated attributes may be obtained in a matter of minutes.

The forest inventory data base currently utilizes approximately 30 IGDS levels, separating such details as aerial photo centres, topography, toponymy, cadastral survey, forest type polygons and their descriptions, etc. Each forest type polygon is associated with an attribute list containing map sheet and polygon number, species composition, age, height, and crown closure, number of stems per hectare, environmental constraints and other relevant descriptive information. The process of digitizing is completely automated by combinations of IGDS and user-developed algorithms integrated to produce maps and reports in accordance with provincial and Forest Service standards. Map labels describing forest types are loaded through the attribute file and placed at the text nodes associated with the unique polygon numbers. The Data Management and Retrieval System (DMRS) software calculates the areas of the close forest-type polygons and enters this information into the attribute file. The graphic designs or maps are plotted on mylar and two copies are made; one goes to the relevant district and the other is kept at the Inventory Branch. Future changes are then marked on the district's copy and the design and attribute files are updated on an annual basis thereafter.

Currently two types of manuscripts are being digitized, i.e., the existing 1:15 840 maps with English unit labels and the new 1:20 000 and 1:10 000 series with S.I. unit labels covering the re-inventoried areas. The time required to digitize an average forest cover map, consisting of planimetric, cadastral and thematic details (approximately 800 polygons), was originally estimated to be 11-12 hours of uninterrupted production. Because of staff training and vacancies, it has not been possible to maintain this production goal consistently, although it has been achieved with experienced staff on numerous occasions. The corresponding time to draw a map manually is about 40 hours; hence, there is a substantial increase in throughput when an IGDS is used. However, IGDS provides the highest benefit:cost ratio during the update stage, when changes can be implemented in terms of minutes, followed by approximately 30 minutes of plotting.

The staffing for IGDS is organized to maximize throughput. Two persons are assigned to each design/digitizer station and their time is scheduled for the continuous operation of the system. Time off the system is spent on preparation, quality control and other relevant activities.

DATA MANAGEMENT AND UPDATE

The IGDS has its own data management and retrieval capability, facilitating graphics and attribute file searches, overlays of levels within a file as well as several files, and efficient updates. In addition, the graphics data base is summarized in terms of 100-hectare grids and is being set up on the IBM computer under the MARK IV data management system.

Since recent legislation requires annual updates of forest type maps and statistics, there are serious operational problems in handling a data base as large as that of the province of British Columbia. The tool currently used for the update is supplementary aerial photography obtained with Hasselblad cameras from helicopters. The scale for supplementary photography is generally 1:5 000 or 1:10 000 but other variations are often used to meet local objectives. At present, there are two sets of cameras with platform and related equipment owned by the British Columbia Forest Service and an order has been placed to acquire five additional sets. Hence, it will be possible to decentralize this function by providing one set of cameras to each of six regions. Disturbed areas can then be updated within a short time by renting a helicopter, attaching the fully equipped camera platform, and obtaining high altitude photographs to map the extent of the disturbance; however, at the same time, low altitude stereo pairs may also be obtained from the same area to provide a quantitative description of ground conditions, such as volume of timber in a residual stand after logging, regeneration, etc.

During the past few years, the Inventory Branch has carried out operational trials to test the applicability of satellite image analysis for classification, sampling and update. The results of these tests indicate that satellite image analysis has a great potential for application in forest and range inventory. However, the current state of the art limits a full scale operational application in British Columbia.

POTENTIAL USE OF A SATELLITE IMAGE ANALYSIS SYSTEM

Specifications for a satellite image analysis system must be defined in terms of both present and future use and in an operational context. Hence, the system must be capable of performing operational tasks in the following areas:

(1) updates of disturbed areas, e.g. logging, windblow, insect attack, etc.

(2) classification of forest and range lands in accordance with the existing classification system

(3) monitoring the changes in the data base.

Because of the large volume of data which must be processed at high speed, a satellite image analysis system which the Inventory Branch would consider for acquisition must be capable of classifying images at a high degree of accuracy, processing large volumes of data at high speed (high throughout), performing "turnkey" operations with existing staff, and operating with several terminals, and it must be compatible with the Inventory Branch's IGDS.

The IGDS data base contains inventory data in UTM coordinates. These data consist of field and photo samples, as well as boundaries and descriptive statistics of each stratum. A satellite image analysis system must be capable of utilizing this information for training and classifying.

Discussion

In answer to a question concerning the cost of updating the British Columbia Forest Service Inventory System, a figure of $1.5 million was given. The program currently involves 126 permanent staff at provincial headquarters and another 24 in the regions. The operating budget is $6 million annually.

Each regional headquarters has a remote computer terminal which permits the rapid acquisition of up-to-date inventory information.

CHOICE OF SCALE FOR FRI PHOTOGRAPHY

A. Jano, Environmental Specialist
Ontario Centre for Remote Sensing
Ontario Ministry of Natural Resources
Toronto, Ontario

To evaluate the effect of photographic scales on the quality of photointerpretation for forest inventory purposes, eight sets of inventory records, based on forest typing by two interpreters using four different photographic scales, were produced. Comparisons of the individual records with an independent inventory are presented. Use of the 1:10 000 scale is suggested for the complex forest types of the tolerant hardwood region of Ontario.

Afin d'évaluer l'effet des échelles photographiques sur la qualité de la photo-interprétation à des fins d'inventaire forestier, huit séries de rapports d'inventaires étayés sur la détermination des types forestiers par deux interprètes utilisant différentes échelles photographiques, ont été présentées. L'auteur présente des comparaisons de différents rapports avec un inventaire indépendant. Il suggère d'utiliser l'échelle 1:10 000 pour les types forestiers complexes de la région des feuillus d'ombre de l'Ontario.

As part of the process of conversion to the international system of measurement, the scale of 4 inches to 1 mile (1:15 840) that has long been used for aerial photographs in Ontario will be replaced by one of the recommended metric scales. However, many issues will have to be examined before a final decision can be made with respect to the new scale.

With the support of the Forest Resources Group of the Ontario Ministry of Natural Resources (OMNR), the Ontario Centre for Remote Sensing (OCRS) undertook a study on one aspect of choosing a new scale for provincial aerial photography: namely, the effect of scale on quality of photointerpretation. The study was conducted for the Forest Resources Inventory (FRI), one of the main users of aerial photography.

NOTE: This paper is part of a study that was begun several years ago. In order that the results might be compared directly with those obtained earlier and with the last official inventories of the area in question, English units are used throughout the paper.

So far, a variety of scales ranging from 1:10 000 to 1:20 000, each with advantages and disadvantages, has been suggested. The Ontario Centre for Remote Sensing suggested two different photographic scales, 1:10 000 for southern Ontario and 1:20 000 for northern Ontario. The reasoning behind this suggestion is that accurate interpretation of the relatively complex forest cover typical of southern Ontario requires greater photographic detail than that provided by the present scale, while the forest types of the boreal region are simple, and therefore one could reasonably expect sufficient precision of interpretation for this region from smaller scales.

This assumption has not yet been proven. The purpose of the OCRS scale test is to evaluate it. Before the details of the test are given, it is important to reiterate that the purpose of this study is to evaluate the effect of scale on the quality of photointerpretation--and nothing more.

METHOD OF INVESTIGATION

Two test areas were selected for the study, one in Algonquin Park and the other in the Englehart Management Unit (boreal region). Photography for both sites was planned for the summer of 1978. For various reasons, only the Algonquin site was photographed in 1978.

The Algonquin test site is located in Devine and Bishop townships. It is a single line with a net area of approximately 13,000 acres.

Panchromatic photography of the test area was acquired on 31 August, 1978 at the scales 1: 10 000, 1:12 500, 1:15 840, and 1:20 000.

Recent ground data were available. Thirteen FRI ground plots were located in the area, and operational cruise data from 32 plots were also available.

The interpretation was carried out independently by two interpreters. The FRI ground information was transferred to each set of photographs. The four sets were interpreted and typed in the following order: 1:15 840, 1:20 000, 1:10 000 and 1:12 500. Approximately one month was allowed to elapse between successive interpretations to ensure that they were done independently. The interpreters were told which scale they were using so that they could estimate height at all scales.

From the four sets of typed photographs produced by each interpreter (all sets covering the same area), eight sets of regular FRI reports were produced using standard FRI procedures.

COMPARISON OF THE EIGHT INDEPENDENT INTERPRETATIONS

From the beginning of this project, the difficulties in using an experimental design that would permit statistical analysis of the independent inventories were recognized.

In the first place, there was a lack of proper ground truth. Without a comparable standard, comparison could be made only between the different interpreters or the different scales. This was not the purpose of the study. Moreover, we had no reason whatsoever to accept any of the eight inventories as correct.

In the second place, because of time constraints, the test could not be extended to include an evaluation of independent interpretations by one interpreter using each scale several times. It is true that the independence of the last few of, say, 16 interpretations of the same area by one person would be questionable anyway. Nevertheless, a significant source of variation has not been investigated.

With these shortcomings in mind, one can proceed to analyze the results in a semi-scientific manner.

The operational cruise data were taken as the basis for comparison. These data certainly were not ideal for the purpose, as the FRI inventory and the operational cruise serve different purposes and provide different information. The only common ground is the gross total volume (GTV) by species as the operational cruise does not provide any information on working groups or age classes. However, for the FRI, the GTV is of secondary importance; it is relative to correct working group and, consequently, to species identification and correct age determination.

Furthermore, the operational cruise was designed to sample only the tolerant hardwood and hemlock working groups as determined by an earlier FRI inventory, while the inventories to be compared included all working groups in the area. Therefore, the GTV figures of the operational cruise were compared both to the gross volume figures of the FRI for the entire study area and to those for the working groups sampled by the operational cruise.

In view of all these qualifications, the operational cruise results cannot be considered definitive. The operational cruise sampling error for this area was somewhat less than 10%. In all comparisons this figure was taken into account for calculating the upper and lower limits of the estimates.

A comparison on a stand by stand basis would be desirable because the stand is the basic unit of inventory and interpretation. Unfortunately, this is not possible, because stand delineation changes with each interpretation made, and because no ground truth is available on this basis.

A comparison on the basis of GTV by species seems the most appropriate.

COMPARISON OF AREA CLASSIFICATION

As may be expected, there are no significant differences among the inventories in the area classification (Table 1). Small differences in the estimates of production forest area may be due to errors in area determination. The only real difference between interpreters is in the classification of old logging roads that were identified either as unclassified land or as barren and scattered forest land. Scale had no influence on area classification.

Table 1. Comparison of area summaries.

		Size of area by class (acres)							
Interpreter	Scale	Production forest	Protection forest	Barren and scattered	Treed bog	Open bog	Unclassified land	Water	Total
A	1:10 000	9 938	-	972	102	456	328	944	12 740
	1:12 500	9 694	-	1 156	104	482	328	976	12 740
	1:15 840	9 766	-	1 040	112	592	280	950	12 740
	1:20 000	9 906	-	1 038	120	498	222	956	12 740
B	1:10 000	9 886	222	1 016	-	572	-	1 044	12 740
	1:12 500	10 024	108	1 028	14	516	-	1 050	12 740
	1:15 840	9 994	318	858	36	662	-	952	12 740
	1:20 000	9 776	186	1 010	52	726	-	990	12 740

COMPARISON OF AVERAGE STAND SIZE

Concern that typing photographs with scales larger than 1:15 840 would lead to a decrease proportional to scale in stand size, causing problems in drafting and lettering of stands, seems to be unfounded. Analysis of the average stand sizes typed at different scales indicates that the complexity of the forest cover and the degree to which it is recognized are the governing factors in stand delineation.

In Table 2, "actual" stand size refers to the average stand size typed at each scale. "Calculated" stand size refers to the average of the average stand typed on the 1:15 840 scale photographs calculated at each scale.

At the 1:20 000 scale, both interpreters typed larger stands than they typed at the 1:15 840 scale. The increase in stand area in the case of one interpreter was only marginal.

Table 2. Average size of forest type by interpreter and map scale.

	Stand size (acres)			
	Interpreter A		Interpreter B	
Map scale	Calculated	Actual	Calculated	Actual
1:10 000	33	70	32	58
1:12 500	52	62	50	54
1:15 840	83	83	80	80
1:20 000	132	125	126	85

As one moves toward the larger scales, the average stand size decreases. The decrease is significantly smaller than one could expect on the basis of scale. Alone, it most likely results from the fact that the increased scale reveals additional detail sufficient to break up larger stands into smaller ones. Homogeneous stands were left unchanged, regardless of the scale.

The unexpected increase of stand size at the 1:10 000 scale in comparison with the 1:12 500 scale occurred because the 1:10 000 scale photos were typed up to the frame edge without any additional coverage. Consequently, small areas that would have been typed as part of stands outside the test area boundary were lumped together with the surrounding stands.

COMPARISON OF SCALES FOR SPECIES RECOGNITION

This comparison is based on the GTV figures of the different interpretations and on those of the operational cruise. The tabulated values (GTV and % GTV) are found in Tables 3 and 4.

There were no startling differences with respect to species recognition between interpreters or between scales. The major species were always identified correctly. In the case of minor species, however, one interpreter consistently mistook poplar for red pine, and did not recognize white pine on the smallest scale. Larch was mistaken for ash, again at the smallest scale. (Neither red pine nor ash was found in the area by the operational survey.)

White Spruce (7.6% operational cruise)

The white spruce component (both in the operational cruise working groups and in the entire area) showed a steady increase with the increase of scale. Apparently, the higher resolution of the larger scales permits better recognition of white spruce in mixed stands.

Table 3. Species recognition based on gross total volume for all forest types by interpreter and map scale.

Species[a]	Gross total volume - 100s of cunits (%)								
	Interpreter A				Interpreter B				Operational cruise
	1:10 000	1:12 500	1:15 840	1:20 000	1:10 000	1:12 500	1:15 840	1:20 000	
Pw	1.5 (0.1)	1.6 (0.1)	5.6 (0.2)	- (-)	24.6 (1.1)	14.8 (0.7)	9.4 (0.4)	7.0 (0.3)	7.9 (0.4)
Pr	15.5 (0.6)	21.7 (0.9)	26.6 (1.1)	5.5 (0.2)	- (-)	- (-)	- (-)	- (-)	- (-)
Sb	99.0 (4.0)	117.0 (4.9)	90.5 (3.7)	98.2 (4.2)	198.3 (8.7)	228.2(10.5)	181.2 (8.1)	214.4 (8.8)	121.1 (5.5)
Sw	250.5 (10.2)	228.7 (9.6)	209.6 (8.6)	178.3 (7.6)	162.7 (7.1)	136.3 (6.3)	123.6 (5.5)	119.6 (4.9)	160.0 (7.3)
B	155.6 (6.4)	141.3 (5.9)	105.0 (4.3)	113.0 (4.8)	65.7 (2.9)	45.8 (2.1)	54.1 (2.4)	86.8 (3.5)	93.6 (4.3)
He	25.9 (1.1)	13.4 (0.6)	38.6 (1.6)	49.1 (2.1)	76.2 (3.3)	70.9 (3.3)	24.9 (1.1)	83.1 (3.4)	173.7 (7.9)
Ce	5.1 (0.2)	5.3 (0.2)	5.2 (0.2)	5.1 (0.2)	38.2 (1.7)	28.8 (1.3)	9.0 (0.4)	54.9 (2.2)	89.2 (4.1)
L	1.3 (0.1)	- (-)	1.4 (0.1)	- (-)	3.7 (0.2)	0.7 (-)	3.2 (0.1)	.8 (-)	- (-)
Po	- (-)	- (-)	- (-)	13.4 (0.6)	27.6 (1.2)	39.4 (1.8)	29.7 (1.3)	48.7 (2.0)	- (-)
Bw	3.6 (0.1)	1.6 (0.1)	14.7 (0.6)	10.5 (0.4)	5.4 (0.2)	6.7 (0.3)	11.2 (0.5)	10.2 (0.4)	8.4 (0.4)
Mh	951.4 (38.8)	918.9 (38.6)	1003.3 (41.0)	917.2 (39.3)	1106.8 (48.4)	1104.2(50.9)	1224.0(54.7)	1191.8 (48.6)	1017.7 (46.4)
By	567.7 (23.2)	567.1 (23.8)	535.0 (21.9)	554.1 (23.7)	402.0 (17.6)	347.3(16.0)	391.8(17.5)	437.4 (17.9)	368.8 (16.8)
Be	100.7 (4.1)	99.6 (4.2)	135.0 (5.5)	62.1 (2.7)	25.0 (1.1)	3.2 (0.1)	31.3 (1.4)	17.1 (0.7)	80.7 (3.7)
Bd	10.2 (0.4)	3.9 (0.2)	29.8 (1.2)	21.2 (0.9)	- (-)	- (-)	- (-)	1.3 (0.1)	- (-)
Or	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)	1.1 (-)	- (-)	- (-)
A	- (-)	- (-)	- (-)	0.2 (-)	- (-)	- (-)	- (-)	- (-)	- (-)
Ms	262.2 (10.7)	262.5 (11.0)	245.3 (10.0)	308.9 (13.2)	148.4 (6.5)	140.1 (6.5)	143.2 (6.4)	175.8 (7.2)	74.1 (3.4)
Oh	- (-)	- (-)	- (-)	-- (-)	0.5 (-)	0.9 (-)	- (-)	1.0 (-)	- (-)
TOTAL	2450.2(100.0)	2382.6(100.1)	2445.6(100.0)	2336.8 (99.9)	2285.1(100.0)	2167.3(99.8)	2237.7(99.8)	2449.9(100.0)	2195.2(100.2)

[a] Pw = white pine, Pr = red pine, Sb = black spruce, Sw = white spruce, B = birch, He = hemlock, Ce = cedar, L = larch, Po = poplar, Bw = white birch, Mh = hard maple, By = yellow birch, Be = beech, Bd = basswood, Or = red oak, A = aspen, Ms = sugar maple, Oh = other hardwoods.

Table 4. Species recognition based on gross total volume in the tolerant hardwood and hemlock working groups by interpreter and map scale.

Species[a]	Gross total volume - 100s of cunits (%)								
	Interpreter A				Interpreter B				Operational cruise
	1:10 000	1:12 500	1:15 840	1:20 000	1:10 000	1:12 500	1:15 840	1:20 000	
Pw	1.5 (0.1)	1.6 (0.1)	5.6 (0.3)	- (-)	18.4 (1.0)	11.4 (0.6)	9.4 (0.5)	2.0 (0.1)	7.9 (0.4)
Pr	0.4 (0.0)	1.2 (0.1)	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)
Sb	4.4 (0.2)	13.0 (0.6)	8.2 (0.4)	25.4 (1.2)	13.4 (0.7)	15.4 (0.9)	25.1 (1.3)	37.1 (1.8)	12.1 (0.6)
Sw	166.3 (7.7)	155.2 (7.4)	131.8 (6.1)	115.5 (5.4)	74.2 (4.0)	72.1 (4.1)	43.4 (2.3)	40.0 (1.9)	160.0 (7.6)
B	108.2 (5.0)	97.8 (4.7)	65.6 (3.0)	94.3 (4.4)	6.7 (0.4)	9.2 (0.5)	18.2 (1.0)	38.2 (1.9)	93.6 (4.5)
He	25.9 (1.2)	13.4 (0.6)	37.2 (1.7)	49.1 (2.3)	75.7 (4.1)	69.3 (3.9)	24.9 (1.3)	83.1 (4.0)	173.7 (8.3)
Ce	2.4 (0.1)	2.6 (0.1)	2.3 (0.1)	2.8 (0.1)	18.7 (1.0)	23.2 (1.3)	8.0 (0.4)	50.1 (2.4)	89.2 (4.3)
L	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)
Po	- (-)	- (-)	7.6 (0.3)	13.4 (0.6)	1.7 (0.1)	2.5 (0.1)	0.6 (0.0)	11.7 (0.6)	- (-)
Bw	0.5 (0.0)	0.9 (0.0)	8.8 (0.4)	10.5 (0.5)	1.2 (0.1)	4.0 (0.2)	2.4 (0.1)	.4 (0.0)	8.4 (0.4)
Mh	946.5 (43.7)	911.7 (43.5)	996.8 (45.8)	909.6 (42.7)	1103.0 (59.7)	1031.3(62.5)	1216.5(64.1)	1179.2(57.4)	1017.7 (48.8)
By	551.2 (25.5)	544.2 (26.0)	519.8 (23.9)	522.5 (24.5)	381.0 (20.6)	327.8(18.6)	382.3(20.1)	432.6(21.0)	368.8 (17.7)
Be	100.7 (4.7)	99.6 (4.8)	135.0 (6.2)	62.1 (2.9)	25.0 (1.4)	3.2 (0.2)	31.3 (1.6)	17.1 (0.8)	80.7 (3.9)
Bd	10.2 (0.5)	3.9 (0.2)	29.8 (1.4)	21.2 (1.0)	- (-)	- (-)	- (-)	- (-)	- (-)
Or	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)	1.1 (0.1)	- (-)	- (-)
A	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)
Ms	246.7 (11.4)	248.4 (11.9)	228.1 (10.5)	304.0 (14.3)	129.2 (7.0)	123.2 (7.0)	135.3 (7.1)	163.4 (7.9)	74.1 (3.5)
Oh	- (-)	- (-)	- (-)	0.5 (-)	0.5 (0.0)	0.9 (0.0)	- (-)	1.0 (0.0)	- (-)
TOTAL	2164.9 (100.1)	2093.5(100.0)	2176.6(100.1)	2130.9 (99.9)	1848.7(100.1)	1693.5(99.9)	1898.5(99.9)	2055.9(99.8)	2086.2(100.0)
Area (ac)	8036	7912	7960	8148	7686	7840	7795	7976	9863
Yield (cunits/ac)	26.9	26.4	27.3	26.1	24.1	21.6	24.4	25.8	21.2

[a] Pw = white pine, Pr = red pine, Sb = black spruce, Sw = white spruce, B = birch, He = hemlock, Ce = cedar, L = larch, Po = poplar, Bw = white birch, Mh = hard maple, By = yellow birch, Be = beech, Bd = basswood, Or = red oak, A = aspen, Ms = sugar maple, Oh = other hardwoods.

Black Spruce (0.6% operational cruise)

Black spruce, which was a very small component of the hardwood and hemlock working groups, was consistently estimated at percentages close to the operational cruise figures.

Balsam Fir (4.5% operational cruise)

The B component changed in a manner similar to white spruce with the changing scale. In one set of inventories the trend was less clear than in the other.

Hemlock (8.8% operational cruise)

Recognition of the proportion of hemlock, both as a working group and as a component in other working groups, also increased with the increase in scale. Even so, in comparison with the operational cruise, both interpreters underestimated the hemlock content of the study area. The highest proportion of hemlock (by volume) was found at the smallest scale in both sets. However, at this scale one interpreter assigned no area to this working group, and the other had significantly larger hemlock working groups at the two larger scales. Therefore, the high figures must have come from the hemlock components of the large hardwood stands delineated at the 1:20 000 scale.

White Cedar (4.3% operational cruise)

White cedar is another species underestimated by the interpreters, in comparison with the operational cruise. Much of what was said about hemlock applies to cedar as well. Its recognition as a minor component is difficult at all scales.

White Pine (0.4% operational cruise)

As a minor species in the study area, white pine was largely unrecognized. On one set, it was underestimated and missed completely at the smallest scale. On the other set, its proportion continuously increased with scale. For this species, the operational cruise figures were too low, as white pine was concentrated in a few stands, none of which was sampled by the operational cruise.

Confusion between hemlock and white pine was minimized at the two larger scales. For example, one small stand was classified in the white pine working group at 1:20 000 (Pw_4 By_3 Mh_2 Ms_1), transferred to the hard maple working group (Mh_4 Pw_3 By_2 Hc_1) with some hemlock in it at 1:15 840, and finally placed where it belonged—in the hemlock working group—at the two largest scales (He_4 Mh_3 By_2 Sw_1 at 1:12 500; He_4 Mh_2 By_3 Sw_1 at 1:10 000). As the stand boundaries were not identical, all four descriptions could be valid, although the two conifer species should not have been confused.

Hard Maple (48.8% operational cruise)

Both interpreters were highly consistent in their estimates of the hard maple component, one underestimating it, the other overestimating it, in comparison with the operational cruise figure. There is little or no change with scale.

Yellow Birch (17.7% operational cruise)

As with hard maple, this major component was estimated by both interpreters with high consistency. Both overestimated yellow birch to some degree, one being slightly over the 10% limit. There was no change with scale.

Beech (39% operational cruise)

Beech was very slightly overestimated by one interpreter, with the estimates from the two largest scales being closest to the operational cruise estimate. The other interpreter consistently underestimated the beech component. No apparent connection with scale was found.

Soft Maple (3.5% operational cruise)

Both interpreters overestimated soft maple consistently at all scales, by factors of 2 and 3, respectively. This could conceivably have been due to the time of year at which the photographs were taken. Soft maple was very conspicuous because of the color change.

Gross Total Volume

In general, GTV was overestimated by both interpreters at all scales. Estimates 006, 007 and 008 were all within the limits of the operational cruise, estimate 007 (scale 1:12 500) being the closest.

COMPARISON OF WORKING GROUP DETERMINATION

Areas and volumes of all major working groups (hard maple, yellow birch, hemlock, spruce) were determined consistently by both interpreters. Because of the nature of the operational cruise data, no comparison can be made on this basis. It appears that the photographic scale has no effect on the determination of major working groups.

Working group areas are given in Table 5; volumes are given in Table 6.

Table 5. Area assigned to major working groups by interpreter and map scale.

Working group[a]	Area - acres (%)							
	Interpreter A				Interpreter B			
	1:10 000	1:12 500	1:15 840	1:20 000	1:10 000	1:12 500	1:15 840	1:20 000
Pw	- (-)	- (-)	- (-)	- (-)	56 (0.6)	30 (0.3)	- (-)	40 (0.4)
Pr	88 (0.9)	136 (1.4)	104 (1.1)	- (-)	- (-)	- (-)	- (-)	- (-)
S	1608 (16.2)	1480 (15.3)	1602 (16.4)	1674 (16.9)	1904 (19.3)	1948(19.2)	1958 (19.7)	1602 (16.4)
B	206 (2.1)	166 (1.7)	100 (1.0)	84 (0.8)	- (-)	24 (0.2)	- (-)	22 (0.2)
He	- (-)	- (-)	- (-)	- (-)	242 (2.4)	408 (4.0)	60 (0.6)	54 (0.6)
Ce	- (-)	- (-)	- (-)	- (-)	104 (1.1)	46 (0.5)	- (-)	- (-)
Po	- (-)	- (-)	- (-)	- (-)	136 (1.4)	244 (2.4)	188 (1.9)	158 (1.6)
Bw	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)	20 (0.2)	- (-)
Mh	6102 (61.4)	5946 (61.3)	6038 (61.8)	5856 (59.1)	5778 (58.4)	6066(59.9)	6302 (63.3)	6222 (63.5)
By	1044 (10.5)	884 (9.1)	1242 (12.7)	988 (10.0)	1128 (11.4)	744 (7.3)	812 (8.2)	978 (10.0)
Oh	890 (9.0)	1082 (11.2)	680 (7.0)	1304 (13.2)	538 (5.4)	622 (6.1)	621 (6.2)	722 (7.4)
TOTAL	9938(100.1)	9694(100.0)	9766(100.0)	9906(100.0)	9886(100.0)	10132(99.9)	9961(100.1)	9798(100.1)

[a] Pw = white pine, Pr = red pine, S = spruce, B = birch, He = hemlock, Ce = cedar, Po = poplar, Bw = white birch, Mh = hard maple, By = yellow birch, Oh = other hardwoods.

Table 6. Gross total volumes assigned to major working groups by interpreter and scale of photography.

Working group[a]	Gross total volume - 100s of cunits (%)							
	Interpreter A				Interpreter B			
	1:10 000	1:12 500	1:15 840	1:20 000	1:10 000	1:12 500	1:15 840	1:20 000
Pw	-	- (-)	- (-)	- (-)	51.9 (2.2)	10.0 (0.5)	13.1 (0.6)	16.0 (0.7)
Pr	24.3 (1.0)	38.8 (1.6)	36.1 (1.5)	-	- (-)	- (-)	- (-)	- (-)
S	244.1 (10.0)	238.2(10.0)	231.9 (9.7)	199.9 (8.6)	370.7(16.0)	328.9(15.2)	299.2 (13.3)	339.2 (13.8)
B	17.0 (0.7)	12.2 (0.5)	8.5 (0.4)	6.5 (0.3)	- (-)	7.4 (0.3)	2.4 (0.1)	- (-)
He	- (-)	- (-)	- (-)	- (-)	51.9 (2.2)	99.6 (4.6)	13.1 (0.6)	16.0 (0.7)
Ce	- (-)	- (-)	- (-)	- (-)	10.3 (0.4)	2.5 (0.1)	- (-)	- (-)
Po	- (-)	- (-)	- (-)	- (-)	34.7 (1.5)	54.6 (2.5)	34.6 (1.5)	41.1 (1.7)
Bw	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)	3.1 (0.1)	- (-)
Mh	1698.4 (69.3)	1646.1(69.1)	1614.7 (67.5)	1609.8 (68.9)	1477.1(63.8)	1394.2(64.3)	1611.7 (71.6)	1698.4 (69.2)
By	275.4 (11.2)	227.2 (9.5)	363.7 (15.2)	250.0 (10.7)	220.8 (9.6)	152.6 (7.0)	165.9 (7.4)	218.2 (8.9)
Oh	190.9 (7.8)	220.2 (9.2)	138.4 (5.8)	270.7 (11.6)	98.0 (4.2)	117.0 (5.4)	107.6 (4.8)	124.7 (5.1)
TOTAL	2450.1(100.0)	2382.7(99.9)	2393.3(100.1)	2336.9(100.1)	2315.4(99.9)	2166.8(99.9)	2250.7(100.0)	2453.6(100.1)

[a] Pw = white pine, Pr = red pine, S = spruce, B = birch, He = hemlock, Ce = cedar, Po = poplar, Bw = white birch, Mh = hard maple, By = yellow birch, Oh = other hardwoods

AGE DETERMINATION

For the evaluation of stand age determination at different scales, the operational cruise data contained no comparable information.

Areas in the different age classes of the major working groups (Table 7) indicate that age estimation is fairly consistent regardless of scale. In the hard maple, yellow birch, and other hardwoods working groups, the majority (90% or more) of the stands were in the 121+ age class. This fact is responsible to some degree for the consistency.

Areas in the spruce working group were more evenly distributed among the age classes. Even in this case, one interpreter was very consistent in estimating ages.

Age determination also appears to be independent of the photographic scale. This was expected to be the case, since stand age estimates are based on available ground data, site, stand height and condition, none of which could be better estimated at any particular scale in the range being studied.

CONCLUSIONS

The results of comparing FRI inventories produced from photography of different scales lead to the following conclusions:

1. There is no significant difference among photographic scales with respect to stand ages or to area and volume determination of major working groups.

2. Species recognition is improved with increasing photographic scale.

3. Recognition of minor species in mixed stands is considerably improved with increasing scales.

4. The higher resolution of the larger photographic scales results in a larger number of more precisely defined stands.

The study is not complete without an evaluation of a similar set of inventories for a boreal test area. This information is expected to be available for analysis in early 1980. At this point the results seem to support the OCRS recommendation for the choice of photographic scales.

Table 7. Area assigned to various age classes by working group, interpreter, and scale of photography.

Working group[a]	Age class	Area – acres (%)							
		Interpreter A				Interpreter B			
		1:10 000	1:12 500	1:15 840	1:20 000	1:10 000	1:12 500	1:15 840	1:20 000
H	B/S[b]								
	21-40								
	41-60					40 (7.4)	30 (4.8)		
	61-80	20 (2.2)		134 (19.8)	224 (17.2)				
	81-100	852 (95.7)	1018 (94.1)	532 (78.5)	574 (44.0)	172 (32.0)	206 (33.1)	318 (52.0)	344 (47.6)
	101-120	18 (2.0)	64 (5.9)	12 (1.8)	116 (8.9)	296 (55.0)	386 (62.1)	180 (29.4)	330 (45.7)
	121-				390 (29.9)	30 (5.6)		114 (18.6)	48 (6.6)
	TOTAL	890 (99.9)	1082(100.0)	678(100.1)	1304(100.0)	538(100.0)	622(100.0)	612(100.0)	722 (99.9)
By	B/S	20 (1.9)	8 (0.9)						
	21-40								
	41-60					10 (0.9)	18 (2.4)		
	61-80			70 (5.6)					
	81-100			2 (0.2)					
	101-120	56 (5.4)	36 (4.1)	42 (3.4)			36 (4.8)		
	121-	968 (92.7)	840 (95.0)	1128 (90.8)	988(100.0)	1118 (99.1)	690 (92.7)	812(100.0)	978(100.0)
	TOTAL	1044(100.0)	884(100.0)	1242(100.0)	988(100.0)	1128(100.0)	744 (99.9)	812(100.0)	978(100.0)
Mh	B/S					36 (0.6)	50 (0.8)		
	21-40								
	41-60					196 (3.4)	296 (5.0)	380 (6.0)	266 (4.3)
	61-80	354 (5.8)	370 (6.2)	516 (8.6)	140 (2.4)	144 (2.5)	132 (2.2)	94 (1.5)	344 (5.5)
	81-100	164 (2.7)	202 (3.4)	48 (0.8)	408 (7.0)	106 (1.8)	10 (0.2)	20 (0.3)	46 (0.7)
	101-120	84 (1.4)	152 (2.6)	82 (1.4)	110 (1.9)	294 (5.1)	630 (10.6)	592 (9.4)	300 (4.8)
	121-	5500 (90.1)	5222 (87.8)	5386 (89.3)	5198 (88.8)	5002 (86.6)	4840 (81.2)	5196 (82.7)	5266 (84.6)
	TOTAL	6102(100.0)	5946(100.0)	6032(100.1)	5856(100.1)	5778(100.0)	5958(100.0)	6202 (99.9)	6222 (99.9)
S	B/S	96 (6.0)	92 (6.2)	150 (9.4)	372 (22.6)	120 (6.3)	184 (9.4)	132 (6.7)	142 (8.9)
	21-40	102 (6.3)	146 (9.9)	152 (9.5)	76 (4.6)	86 (4.5)	224 (11.5)	244 (12.5)	42 (2.6)
	41-60	474 (29.5)	258 (17.4)	746 (46.6)	1070 (65.1)	1296 (68.1)	1206 (61.9)	1230 (62.8)	1036 (64.7)
	61-80	748 (46.5)	788 (53.2)	484 (30.2)	34 (2.1)	258 (13.6)	234 (12.0)	142 (7.3)	284 (17.7)
	81-100	188 (11.7)	196 (13.2)	70 (4.4)	92 (5.6)	144 (7.6)	72 (3.7)	32 (1.6)	72 (4.5)
	101-120						28 (1.4)	178 (9.1)	26 (1.6)
	121-								
	TOTAL	1608(100.0)	1480 (99.9)	1602(100.1)	1644(100.0)	1904(100.1)	1948 (99.9)	1958(100.0)	1602(100.0)

[a] H = hardwood, By = yellow birch, Mh = hard maple, S = spruce.

[b] Barren and scattered.

Discussion

The speaker was asked whether he considered enlargement of small-scale photography or the use of more powerful stereoscopes to be alternatives to photography at different scales. Although both were conceded to be "useful considerations", the objective of the study was to select a metric contact scale for Forest Resources Inventory where two- and four-power stereoscopes are used.

It was also revealed that, at the same time as the black and white coverage was obtained for this study, false color infrared film was used. There were some improvements in species identification using this latter type of film, but it was felt that the infrared film would not improve the measurement of mensurational parameters.

A REVIEW OF THE SUPPLEMENTARY AERIAL PHOTOGRAPHY PROGRAM OF THE ONTARIO MINISTRY OF NATURAL RESOURCES

V.G. Zsilinszky

A.M. Giannelia

and

M.J. Rafelson

Ontario Centre for Remote Sensing
Ontario Ministry of Natural Resources
Toronto, Ontario

Since 1968 supplementary aerial photography (SAP) has been adopted by more than half of the Ontario Ministry of Natural Resources (OMNR) administrative districts. This paper reviews the status of SAP in OMNR, the training received by SAP operators, and the courses of instruction offered by the Ontario Centre for Remote Sensing (OCRS). It also discusses the possibility of standardizing SAP.

Depuis 1968, la photographie aérienne supplémentaire (PAS) a été adoptée par plus de la moitié des districts administratifs du ministère des ressources naturelles de l'Ontario (MRNO). Cet article étudie la situation de la PAS dans le MRNO, la formation donnée aux opérateurs PAS et les cours de formation offerts par le centre ontarien de télédétection (COT). Il étudie aussie la possibilité de standariser la PAS.

INTRODUCTION

Supplementary aerial photography (SAP) was first demonstrated for senior field personnel of the former Ontario Department of Lands and Forests (now the Ontario Ministry of Natural Resources [OMNR]) at Sault Ste. Marie, Ontario early in 1968. The operating procedures were outlined by Zsilinszky (1968). The SAP program was recommended for application to field operations for the following reasons:

1. The equipment required to take stereoscopic aerial photographs and to process prints of a workable size was relatively inexpensive;

2. It was necessary to update provincial survey photography during the 10-year period before new photography was scheduled;

3. Ministry aircraft, when they were not required for life-saving flights or fire control operations, were available for aerial photography;

4. It was feasible to train field technicians to be qualified operators, by means of a basic operational approach;

5. It was difficult to interest aerial survey companies in photographing the small, scattered areas for which field staff required photos because so small a project would be unprofitable.

The Sault Ste. Marie demonstration revealed the potential benefits of SAP to Ministry field personnel. Consequently, district offices proceeded to acquire SAP equipment, and yearly training courses for SAP operators were instituted, from 1969 onward. Additional research results (Zsilinszky 1972a,b,c) on the SAP technique were published. The overall result was the development of a simple, practical aerial photography program.

Now that a decade has passed since the introduction of SAP, it is time to determine the status of the Ministry's SAP program and to consider its future direction.

STATUS

To determine the current status of the SAP program, all 48 district managers of OMNR were contacted by means of a questionnaire. Twenty-six of them, mainly from the northern regions, reported that they were involved in SAP, possessed a camera system and darkroom equipment, and had qualified operators on staff.

Equipment

Altogether there are 26 camera systems in the field--twenty-five 35 mm Nikon camera systems (16 F models and 9 F2 models) and one 70 mm Hasselblad 500 EL/M system. The systems are used for single-camera operations. There are also 26 darkrooms equipped to handle the manual processing of black and white negative films and positive enlargements. The type of aircraft most commonly available is the deHavilland Turboprop Beaver, but occasionally other types of aircraft are used, such as a leased Piper Aztec.

Operations

The majority of SAP assignments are carried out to obtain up-to-date imagery of cutovers, recent burns and the location of new roads.

Photography is often used in the assessment of regeneration and site preparation as well. Missions are occasionally flown for the mapping of floods, the review of pits and quarries, the assessment of forest disease, the mapping of wild rice beds, and the study of cottage development. Miscellaneous tasks may include coverage of water pollution, the results of herbicide spraying, and silvicultural projects.

Since the information plotted or delineated on a SAP photograph is generally transferred to the forest inventory (FRI) map, the most common working scale of SAP is 1:15 840. Seven districts, however, make frequent use of the scale of 1:7 920. Other larger scales, such as 1:3 960, are occasionally used, when close-up detail is the objective. The standard film type is black and white panchromatic, but eight districts also use color films, five occasionally use color infrared film, and two report the use of black and white infrared film.

CONCERNS

Policy

Of the 26 districts for which the questionnaire was completed, 14 reported that obtaining the use of aircraft for SAP is difficult because of the low priority it receives from aircraft dispatchers. However, the dispatchers are merely acting according to the priorities set down in the Ministry's Policy AS1-07-01, in effect since August 20, 1969, on "Dispatching Aircraft". The following is an excerpt from this policy statement:

> "These guidelines will apply when deciding priorities for dispatching aircraft:
>
> 1. Flights involving human life--for example, mercy, search and rescue, evacuation.
>
> 2. Fire control flying--for example, fire service water bombing, patrol, standby in high-hazard periods.
>
> 3. Lands and Forests flying with critical dependence on aircraft at a given time, place and duration for the achievement of objectives--for example, moose census, law enforcement, fish dropping, timber survey or photography.
>
> 4. Flying for other Ontario Government departments..."

SAP is weather-dependent in a way that the other activities given the same level of priority for aircraft use (moose census, law enforcement, etc.) are not. In view of this limitation, the 1969 policy directive does not provide adequate support for the SAP program. It is necessary, therefore, that the appropriate OMNR authorities review this policy, and that SAP be given a separate priority below fire-control flying, but above the other functions listed under priority No. 3, in consideration of the fact that weather conditions, not only time, place and duration, are critical to SAP flying.

Technical

Technical problems indicated in the questionnaires were related to 1) specific operational problems of the operator, and 2) a concern that the quality of a SAP print is expected by many recipients to match that of the provincial survey photography.

Specific problems can be dealt with through a training program such as that discussed later in this paper. However, the question of SAP quality in comparison with full-size survey photography has haunted SAP operations since 1969. The following refutation of the argument that SAP is of little value because it is not equal in quality to survey photography assumes that the SAP print in question is a well processed image of average quality. The questionnaires confirm that the main purpose of SAP is still to update conventional survey photography, which normally involves the plotting or delineating of relatively broad features on the SAP print. For this task, definition less precise than that offered by survey photography is adequate, for two reasons:

1. Linear features, such as a road or the boundary of a burnt forest or of a cutover, produce a pattern that is distinctly visible even with limited contrast and sharpness. A good example of the ease with which linear features can be recorded is the appearance on multispectral scanner (MSS) imagery of the LANDSAT satellite, of a 4-m-wide bulldozed logging road, although the resolution of the MSS is normally 80 m.

2. A survey print may have become outdated for areas that have changed since the date of exposure, but it must remain the basis for photo interpretation of fine detail, such as forest stands. The SAP print is used only to indicate, for example, where a stand no longer exists or where a stand has been altered (e.g., by infestation or disease). Close-up detail is not necessary for extracting this type of information.

If SAP is obtained for a purpose other than updating survey photography, and detail indeed becomes an issue, the only practical solution is to obtain "close-up" photography--that is, to decrease the altitude of the aircraft or increase the focal length of the lens used.

Of course, perfect focusing, clean optics, a fast shutter speed and the choice of a high-resolution film affect the level of detail considerably. However, the fact remains that a 35 mm SAP image has a contact scale of approximately 1:100 000 (24 mm lens/2400 m altitude). To bring this 35 mm contact scale to the 1:15 840 contact scale of conventional survey photography, a linear enlargement of 6.3 times must be performed, and this means that the grain size of the negative will increase 6.3 times as well.

It must be understood that enlargements, regardless of film format, cannot be comparable to contact prints in image sharpness, if both types are of optimum quality. The key question with respect to the quality of SAP is therefore: Is it appropriate to insist upon seeing the trees instead of the forest?

TRAINING

SAP courses have been given nearly every year since 1969, and have been offered by the Ontario Centre for Remote Sensing (OCRS) since its establishment in 1973. Four different opinions on future training were expressed in the questionnaires:

1. OCRS should continue the basic course, but increase the time spent on darkroom work.

2. OCRS should hold refresher courses for individuals who have taken the initial course, but have not had the opportunity to practise the skill often enough to maintain it.

3. A yearly symposium should be held for SAP operators.

4. OCRS should organize an advanced aerial photographic seminar.

The response of OCRS to these comments was to suggest the following training plan:

1. The basic SAP course will continue as a 5-day program, but the curriculum will be revised to incorporate more darkroom work and to make it practical as a refresher course as well. Attendance will be limited to 15 students so that individual attention will be possible.

2. A 3-day workshop will be held once every 2 years. A tentative plan for the workshop will be distributed to the regional directors and district managers early in 1980. The purpose of the workshop will be

   - to foster an exchange of information among SAP operators through presentations and discussion groups

- to identify and strengthen weak areas in the SAP operation

- to demonstrate and introduce new products and methods

- to formulate recommendations on technical, administrative and policy matters.

The first workshop is planned for the fall of 1980.

3. A 3-day advanced aerial photography course will be given only on demand, with a maximum enrollment of 10. This instruction will be offered only to those operators who have already mastered basic SAP and whose district priorities justify the expansion of technology. The first advanced course is planned for early in 1981. It is recommended that, when a group of districts requires more sophisticated SAP capability, the feasibility of having only one regional system to fly special SAP missions for all the districts be considered.

STANDARDIZATION

The SAP operation has become an extensive and still-growing aerial function within OMNR. At present, however, SAP equipment is not uniform across the province. Standardization is desirable for the following reasons:

1. Anything installed in an aircraft must be approved by the Department of Transport. It is more efficient to obtain approval for a single design than for several different designs, all of which serve the same purpose.

2. SAP training will be more effective if the operation of a uniform system can be taught. Standardization will also facilitate effective communication between district operators and OCRS concerning technical difficulties.

Camera Mount

The most critical item for standardization is the camera mount. It must be convenient to use, adaptable to a variety of aircraft hatch sizes, and acceptable from the point of view of aeronautical regulations and operator safety. It would be most desirable for the mount to include the feature of connecting the camera(s) with the aircraft's electric power supply through proper conversion.

A good possibility for the mount is the model recently developed for OCRS, as reported by Zsilinszky (1979). The OCRS mount has been refined to the production stage, and is approved by the Department of Transport.

Camera

SAP camera systems are virtually identical across the province at the present time. SAP began with a combination of components designed to simulate vertical survey photography. The combination found best for the purpose was the motor-driven 35 mm Nikon F. Since the Nikon F camera body and motor were replaced by the F2 model in the early 1970s (although no new lenses were produced), the SAP equipment inventory includes both the F and F2 models. Both are still completely satisfactory in view of the objectives of SAP. However, there is a feeling in some districts that SAP could be improved by replacing the 35 mm film size with the 70 mm format. The usefulness of substituting 70 mm systems is debatable, in view of what is actually demanded of SAP. For the average SAP function, even a 16 mm film size (conventionally called a 110 format) would serve the purpose, if the camera had good optics and offered the same mechanical features as the 35 mm systems. However, if there is a variety of complex photographic projects requiring extensive area coverage and therefore a larger area coverage per frame as well as maximum resolution, acquisition of the more expensive 70 mm-format systems is warranted.

Darkroom

As SAP darkroom procedures are simple and conventional, there is little need to standardize darkroom equipment. It is important, of course, that the darkroom product be uniformly good. It is essential that a SAP darkroom be equipped to maintain the quality of the original photographs, with minimum loss of detail. The most critical SAP darkroom instrument is the enlarger, which must have good optical quality and proper means of projection, a perfectly clean lens, and, most important, perfect focus.

The standardization of SAP requires communication between OCRS, the districts and the Aviation and Fire Management Centre, for the preparation of a detailed plan. OCRS intends to investigate the means of standardization and will make recommendations to the regional directors concerned by the fall of 1980.

CONCLUSIONS

The questionnaire replies received from the districts confirm that the SAP program is for the most part conducted according to the original objectives. The fact that 26 of a total of 48 districts are equipped to perform SAP is evidence of its practical value. (The districts not involved in SAP are located in southern Ontario, where there is less need for aerial coverage because of abundant ground access and limited forest cover.) While the overall impression is positive, it is, nevertheless, essential to recognize existing problems, to determine their significance, and to seek solutions by all available means. For example, it is quite clear that aircraft availability is a problem because of the unduly low priority given to SAP by OMNR policy. The revision of the policy is one way of solving the problem. However, in order to profit from the higher priority, it is important that district staff plan SAP missions with maximum efficiency, so that, when aircraft are provided and weather conditions are favorable, missions may be carried out successfully. In the interest of the most efficient use of aircraft, SAP missions within one region could be coordinated: a crew could obtain photographs for two or three districts while flying its own mission, and the next mission could be the responsibility of another district crew.

With respect to technical problems, the schedule of SAP courses should provide sufficient opportunities for periodic instruction, according to the level of sophistication required. However, it would be useful for the SAP operators to maintain close liaison with OCRS between courses and workshops.

Any aerial photography, but particularly supplementary aerial photography, may fail because of conditions beyond the operator's control--changes in weather, camera malfunction, or defective film--and can be adversely affected by the airsickness or fatigue of the operator. The recipient of SAP should be mindful of the fact that the greatest care and skill cannot always save a mission. However, a district would be wise to minimize the possibility of misfortune by keeping the operation simple until the basic SAP technique is mastered so that it provides a consistently good product. At that point, if there should be a need for more complex types of coverage, the district would be in a position to embark on a more sophisticated aerial photography program.

ACKNOWLEDGMENTS

The cooperation of all OMNR district managers and their staff in responding to the questionnaire which made this review possible is gratefully acknowledged. The valuable suggestions of Mr. W. Cam Stevens, Regional Forester, Northeastern Region and Mr. John L. A. Narraway of OCRS, are greatly appreciated. Appreciation is also extended to Ms. Susan A. Smith of OCRS for manuscript assistance.

LITERATURE CITED

Zsilinszky, V.G. 1968. Supplementary aerial photography with miniature cameras. Pap. presented at Internatl. Congr. Photogram., Lausanne, Switzerland. Photogrammetria (1969/1970) 25:27-38.

Zsilinszky, V.G. 1972a. Camera mounts for 35 mm. mono- and multispectral photography. p. 441-450 *in* Proc. First Can. Symp. on Remote Sensing, Ottawa, Ont.

Zsilinszky, V.G. 1972b. Fisheye lens for plot location. Photogram. Eng. 38(8):773-775.

Zsilinszky, V.G. 1972c. Resource surveys with miniature cameras. Pap. presented at Internatl. Congr. Photogram., Ottawa, Ont., 14 p.

Zsilinszky, V.G. 1979. A user's notes on remote sensing application. Pap. presented at Internatl. Symp. on Remote Sensing for Nat. Resour., Moscow, Idaho. (Proceedings in press)

SESSION IV

Special Applications

Chairman: P.H. Kourtz
Petawawa National Forestry Institute
Canadian Forestry Service
Chalk River, Ontario

SATELLITE MAPPING OF SPRUCE BUDWORM-KILLED BALSAM FIR IN ONTARIO

B.J. Stocks
Project Leader, Fire Research
Department of the Environment
Canadian Forestry Service
Great Lakes Forest Research Centre
Sault Ste. Marie, Ontario

P.H. Kourtz
Research Scientist
Department of the Environment
Canadian Forestry Service
Petawawa National Forestry Institute
Chalk River, Ontario

and

J.B. Todd
Forestry Officer
Department of the Environment
Canadian Forestry Service
Petawawa National Forestry Institute
Chalk River, Ontario

The development of a technique for delineating areas of high balsam fir mortality from satellite imagery is outlined. The mapping of high mortality areas in this fashion will assist forest fire managers in allocating men and resources accordingly.

L'auteur esquisse la mise au point d'une technique pour délimiter les aires de forte mortalité du Sapin baumier à partir de photographies transmises par satellite. Le relevé cartographique des aires de forte mortalité par ce moyen aidera les gestionnaires forestiers préposés à la lutte contre l'incendie à pourvoir les régions en ressources humaines et monétaires selon les besoins.

INTRODUCTION

In recent years, the Ontario Ministry of Natural Resources (OMNR) has become increasingly concerned about the vast areas of balsam fir (*Abies balsamea* [L.] Mill.) mortality, particularly in northeastern Ontario, resulting from the latest outbreak of spruce budworm (*Choristoneura fumiferana* [Clem.]) in the province. Balsam fir is not of great commercial value in Ontario, and large-scale spraying of commercial insecticides has been considered and rejected as a means of controlling budworm populations. As a result, with the exception of isolated spraying in small, high-value areas such as provincial parks, this latest budworm infestation is being permitted to run its course in Ontario. Recent statistics indicate that, to date, approximately 18.5 million hectares have been infested in the province, and balsam fir mortality has occurred on an estimated 7.3 million hectares. It must be remembered, however, that balsam fir densities vary dramatically between and within forest types and it is quite probable that much of this area contains relatively insignificant numbers of dead balsam fir.

Balsam fir grows in a heterogeneous mixture with a variety of deciduous and coniferous species throughout much of Ontario, often as a minor, or understory, stand component. While OMNR forest managers are not overly disturbed about the economic losses resulting from balsam fir mortality, they have become increasingly concerned about the possibility that budworm infestations, with subsequent balsam fir mortality, stand deterioration and dead ground fuel accumulation, create significant fire control problems.

In response to this concern, fire researchers at the Great Lakes Forest Research Centre (GLFRC), in cooperation with the Ministry, have established a series of experimental burning plots in dead balsam fir in the Blind River District. Tree mortality and breakdown, and subsequent ground fuel accumulation, are monitored annually. Experimental fires are being conducted under a broad range of fire weather conditions, in order to develop an index that predicts fire behavior characteristics such as rate of spread, fuel consumption, intensity, crowning and spotting for this fuel type. Both spring and summer fires will be conducted over a number of years before an index is completed. Initial results indicate the potential for explosive crown fires under spring conditions. Summer fires, however, impeded by the lush, green understory vegetation which thrives during stand deterioration, perform weakly.

THE PROBLEM

As OMNR personnel became aware of the potential increase in fire control problems associated with widespread areas of balsam fir mortality, they recognized the need to determine the amount and location of dead balsam fir throughout the province. They felt that, if a reliable method of mapping balsam fir mortality could be developed, it would greatly assist fire control personnel in allocating men and resources when responding to wildfires in areas with significant concentrations of dead balsam fir.

As was mentioned earlier, balsam fir is a secondary or understory species in many forest types and is not always present on provincial Forest Resources Inventory (FRI) maps. In addition, FRI maps are large-scale and not suitable for use in mapping extensive areas. The same problem exists with low-level aerial photographs. The use of satellite photographs, with their extensive cover, seemed an ideal solution to the problem, provided that dead balsam fir could be identified on such small-scale imagery.

Fire researchers at the Petawawa National Forestry Institute (PNFI) have been working on the problem of utilizing satellite imagery to identify and map forest cover types, cutovers and road networks for a number of years and their cooperation was requested in investigating the problem of delineating balsam fir mortality from satellite photographs.

RESEARCH RESULTS

With the cooperation of PNFI fire researchers, a reliable technique for identifying and mapping balsam fir mortality for LANDSAT imagery has been developed and tested in the Gogama District of northeastern Ontario. The technique used involves the overlaying of computer digitized winter LANDSAT frames. The overlaying of two scenes requires the alignment of exact points on two frames taken during different satellite orbits. Once the overlaying is complete, the resulting image is then enhanced, using eight LANDSAT bands, for better separation of ground cover characteristics. As a result of this enhancement, ground features are separated into distinctly different colors that are more easily recognized by the naked eye.

A winter image for the Gogama area taken early in the defoliation period (March 1973) was overlaid with a winter image taken after several years of intense defoliation when widespread mortality was present (January 1976). Any difference between the images would be due to the fact that balsam fir, once defoliated, would appear to resemble a hardwood area during winter. The overlaying technique tends to accentuate areas of disturbance (i.e., areas that have undergone some change during the period between images) such as cutovers, forest fires and defoliation, making them readily discernible.

When enhancement of an image was completed the image was "ground-truthed" by comparison with FRI maps and by ground and helicopter surveillance. Results showed quite clearly that balsam fir mortality could be readily identified, as could pure stands of jack pine and black spruce and areas well stocked to hardwoods such as poplar and birch. It appears that balsam fir must be heavily defoliated or dead if it is to be delineated by means of this technique; it is unlikely that different levels of defoliation could be distinguished.

All of Gogama District has been mapped according to this technique and district personnel have been "ground-truthing" areas since they were provided with imagery.

FUTURE WORK

It seems likely that OMNR fire and forest management personnel in other districts in Ontario would be interested in utilizing this technique for determining the extent of the problem in their area of the province. Once problem areas are located they could be delineated on a large-scale map for easy reference.

This technique is currently being used for mapping areas of severe defoliation and mortality in extensive pure stands of balsam fir in the Cape Breton Highlands region of Nova Scotia and plans are under way to map problem areas experimentally in parts of New Brunswick.

Cost does not appear to be a limiting factor with respect to the future use of this technique; individual OMNR districts could likely be mapped for about $500. At present, however, the equipment and technology needed to implement this approach are being used primarily as research tools. It is hoped that government or commercial agencies will make the necessary investments so that the operational use of satellite imagery in mapping budworm-killed balsam fir can become a reality.

Discussion

It was revealed that this technique of identifying forest stands defoliated by spruce budworm is not sufficiently sensitive to differentiate balsam fir, white or black spruce, although it can distinguish conifers from hardwoods.

APPLICATIONS OF REMOTE SENSING IN FIRE MANAGEMENT IN ONTARIO

G.T. Woods
Fire Management Forester
Aviation and Fire Management Centre
Ontario Ministry of Natural Resources
Sault Ste. Marie, Ontario

Remote sensing technology is used in many facets of fire management, fire suppression decision-making, and planning and resource dispatch in fire centres. Photographs are utilized extensively, and recently, devices such as infrared scanners and LANDSAT satellite images have been introduced in fire operations. These uses should increase as remote sensing technology becomes more affordable and more readily available, and as fire managers become more skilled in their application.

La télédétection est une technique employée dans de nombreux aspects de gestion des feux, de prises de décisions concernant la répression et de planification et d'envoi de ressources aux centres de lutte contre l'incendie. On utilise beaucoup la photographie et récemment, des dispositifs comme le balayage infrarouge et les images par satellite LANDSAT furent introduits dans la répression des incendies. Ces utilisations devraient augmenter à mesure que la technique de télédétection devient moins coûteuse et plus rapidement disponible et à mesure que les gestionnaires en répression deviennent plus habiles dans l'application de la technique.

INTRODUCTION

Fire is a destructive force that devastates valuable forests in Ontario every year. Although fire occurs naturally within the ecosystem, it poses a threat to remote settlements, timber and recreational areas. Each year tens of millions of hectares of forested land in Ontario require costly forest fire protection. Fire managers are often faced with forest fire suppression jobs that place great strains on manpower, suppression equipment, and aircraft inventories. Therefore, managers are constantly seeking affordable technology and information to assist them in making accurate and quick decisions so that they can utilize resources efficiently and keep losses and costs to a minimum.

Remote sensing devices such as cameras have enabled fire management personnel to meet some of the demands placed on them (Fig. 1). Recent technological advances have made the use of remote sensing practicable in many areas of fire management. Remote sensing tools play an important role in individual fires where decisions have to be made on suppression tactics and in fire centres where the use of fire suppression resources is planned and coordinated. The camera continues to be the most widely used remote sensing instrument, but recently, devices such as airborne thermal infrared line scanners, thermal infrared forward-looking scanners, and satellite imagery have been introduced as well.

THE CAMERA

Conventional cameras continue to be used extensively. Photographs taken from the ground or the air are often a source of detail that is not readily available elsewhere. They are used in fire centre operations, fire suppression operations, training programs, historical documentation, and fire investigations.

Aerial photographs are particularly useful. They can be used as mosaics (Astley 1976) or as stereoscopic pairs if more detail is required (Zsilinszky and Graham 1976). Most staff are trained in photo interpretation and accept photos as an indispensable product of remote sensing. Fire managers use up-to-date photographs in fire centre operations to assist them in mapping high-hazard areas such as tornado blowdowns and logging slash. Fire staff also use photos to maintain accurate maps of forest access roads and building locations. Air photos are regularly used during fires as mosaics for plotting fire boundaries (Fig. 2).

Photography, however, has its limitations in fire operations. Commercial aerial photographs are often 5-10 years out of date and therefore do not provide an accurate picture of specific areas of interest. Supplementary aerial photography is often difficult because of weather-related restrictions (such as cloud cover, which can hamper flights). However, even with these obvious limitations cameras and photographs remain important remote sensing tools that provide fire personnel with valuable information.

AIRBORNE THERMAL INFRARED LINE SCANNERS

Several airborne thermal infrared line scanners have been developed for use in fire management operations over the last 15 years (Anon. 1964, 1965, 1979). These devices are used in fire detection and fire mapping. The infrared scanners have day/night operating capabilities and can detect heat radiation through smoke or under partially open forest canopies (Wilson et al. 1971). These are features lacking in

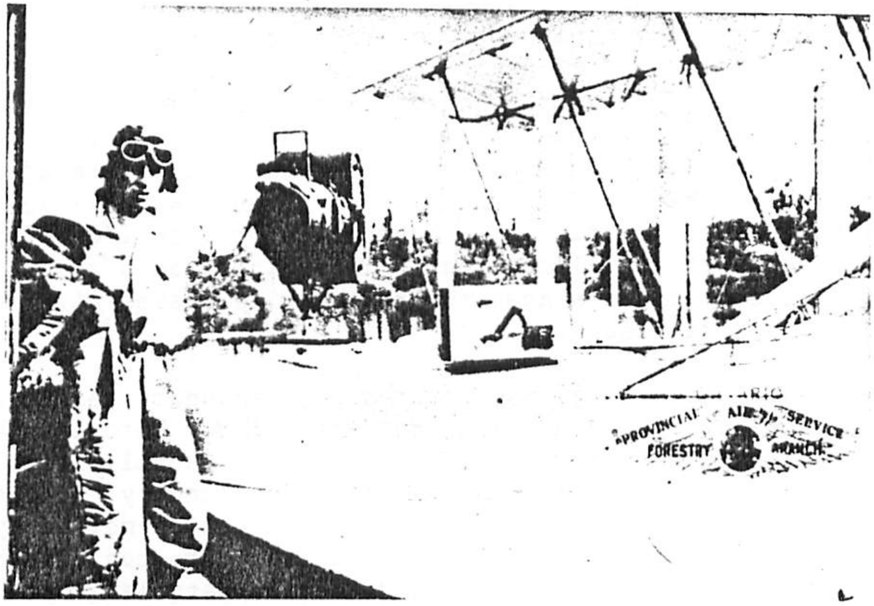


Fig. 1. The first aerial photography camera used in Ontario for forest and fire mapping (1925).

Fig. 2. Aerial photographs in mosaic form assist fire suppression staff in planning strategies.

human fire detectors or mappers, who rely on visual identification. Most of these scanners are equipped with processors and can provide hard-copy illustrations of fire boundaries or locations of isolated fires within minutes. For example, they can provide fire bosses with maps of actively burning portions of the fire edge. They are most useful when fires are large and when the location of the fire edge is extremely critical. They are also handy when extensive smoke prevents human fire mappers from plotting fire boundaries or from identifying new jump fires ahead of the flame front. These infrared scanners can also be used in the postburn stages to provide fire bosses with maps of hot spots along fire lines.

In fire detection programs infrared line scanners permit an expanded detection period and are able to detect fires before smoke is visible. Conventional aerial detection patrols are usually limited to those times when smoke can be seen above the forest canopy. Infrared line scanners can supplement this conventional detection method by providing detection 24 hours a day. Line scanning data can also be used by fire managers in planning aerial detection patrols. With scanning data in hand, aerial observers can anticipate fire locations and plan their patrols accordingly. This integration of systems is particularly useful after lightning storms, when many fires start up simultaneously.

Although there is a substantial demand for these infrared line scanners, the current devices are too costly for extensive use in fire operations. Line scanning units sensitive enough to locate fires in their early stages and to produce satisfactory fire maps are expensive; furthermore, if they are to be used effectively, sophisticated aircraft and highly trained crews will be needed (Astley and Tworzyanski 1974). These units cannot operate if there is cloud cover below the flying altitude of the aircraft. High costs and operating limitations have militated against the widespread use of line scanners in Ontario. Consequently, these devices are used for mapping purposes in fewer than 1% of fires and are not used at all in fire detection programs.

PORTABLE FORWARD-LOOKING THERMAL INFRARED SCANNERS

Portable thermal infrared scanners seem better suited than line scanning devices to present fire operations. Forward-looking scanners are less expensive, and can be operated by fire suppression staff. Unlike line scanners, portable forward-looking scanners are used mainly in postburn operations to assist fire bosses in detecting invisible hot spots along fire lines, a job that usually takes several days to complete by manual line patrol. The ability to detect these smoldering areas early and extinguish the fires quickly is important because it means the time that crews and equipment are required to remain on the fire line for postburn duty can be reduced significantly.

Two models of forward-looking scanners are used in Ontario at present--the AGA Thermovision 750[1] and the Hughes Probeye[2].

The AGA Thermovision 750 is used exclusively as an airborne scanner and is mounted in a light helicopter (Fig. 3). The unit is simple to use and the image interpretation is straightforward, although a certain amount of expertise is required to operate the unit at its optimum level. The AGA has been used extensively in fire suppression operations during the past three fire seasons and has proven to be an effective fire management tool.

The Hughes Probeye has also been used in fire suppression but, unlike the AGA, it has been operated as a ground scanner (Fig. 4) (Myllynen 1977). Operators scan fire edges while walking the fire line, detecting hot spots along the way. This unit is simple to operate, dependable, rugged and relatively inexpensive. Like the AGA, it is now classified as an effective suppression tool.

LANDSAT SATELLITE IMAGERY

LANDSAT imagery was recently introduced to several areas of fire management across the province. It provides general and often preliminary views of forest resources, logging activities, and environmental damage or changes. It has limited use in fire operations.

Some district fire centres now use black and white imagery from band 5 data to map new cutovers and slash areas (Fig. 5). Other districts are using imagery as a reference for water sources that are not marked on conventional maps.

The Provincial Fire Centre and the Ontario Centre for Remote Sensing are currently using LANDSAT scaled at 1:1 000 000 in either black and white from band 5 or false color from bands 4, 5, and 7 to map major cutovers created within the last five years. This has been done in an attempt to maintain a provincial inventory of high hazard and potential prescribed burn areas.

The provincial office, in accordance with its fire history documentation program, is also using LANDSAT to map fires in remote and northern areas of the province.

Several district fire centres are experimenting with a new LANDSAT product, developed by the Canadian Forestry Service's Petawawa National Forestry Institute, which has used the Taylor enhancement technique and the "ARIES" computer system to produce an enhanced LANDSAT image

---

[1] AGA Thermovision is a registered trademark of AGA Infrared Systems AB, AGAtronics Ltd., Sweden.

[2] Hughes Probeye is a registered trademark of Hughes Aircraft Company, Industrial Products Division, California, U.S.A.

Fig. 3

The Agatronics Thermovision 750 mounted in a light helicopter as a two-man operation.

Fig. 4

The Hughes Probeye used as a ground scanning device for detecting hot spots along fire lines.

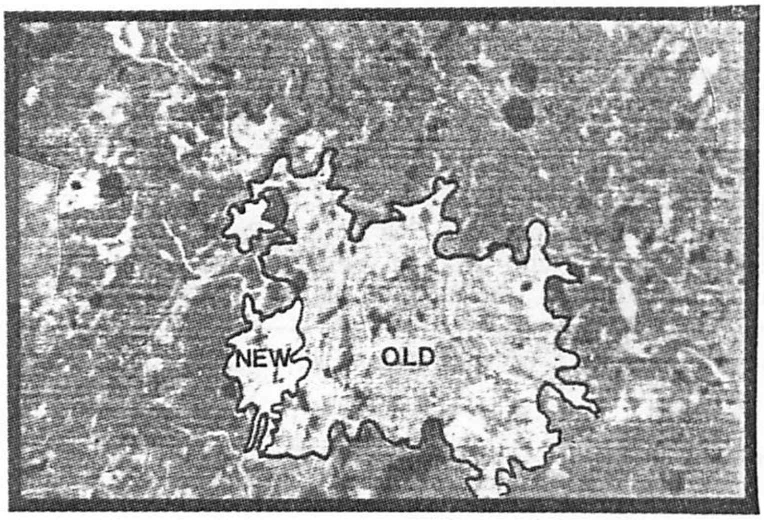


Fig. 5

Old and new cutover shown on LANDSAT black and white band 5 image.

(Kourtz 1977). The total benefits of this new imagery have not yet been realized because it is still being evaluated. Preliminary results show that enhanced color imagery illustrates hardwood and conifer fuel components as clearly as it does water and exposed areas such as roads, swamps, cutovers and rock outcrops. Enhanced black and white imagery clearly illustrates logging roads and cutovers. Field tests indicate that this enhanced imagery has a limited use in providing preliminary views of large areas as well.

Enhanced imagery is also being evaluated for use in identifying extensive areas of forest that have been killed by spruce budworm and therefore constitute a fire hazard. The Petawawa National Forestry Institute has used data overlay and enhancement techniques to produce color-enhanced images that reveal differences in forested areas killed by the spruce budworm. Preliminary evaluation of these products indicates that enhanced imagery can be a useful technique for mapping these volatile areas within the province.

LANDSAT false color transparencies analyzed by analog density slicers have limited use in providing general fuel data for specific areas. The density slicer at the Ontario Centre for Remote Sensing has been used to determine percentages of hardwood, softwood, water, and exposed areas for 115 block areas, each approximately 800 sq. km in size, which, in total, cover most of the North Central Region. These data have been programmed into a fire prediction computer program that is being developed by the Petawawa National Forestry Institute and tested in the North Central Regional Fire Centre. The percentage values of each fuel type are now an important part of the program's data base.

THE FUTURE OF REMOTE SENSING IN FIRE MANAGEMENT

Remote sensing devices will play an increasingly important role in providing information to assist fire staff in utilizing fire suppression resources efficiently and minimizing forest fire losses. Cameras and photographs will continue to be used extensively but progress in this area during the past 10 years clearly indicates that sensors and satellites will play a larger role in future fire management.

Forward-looking infrared scanners such as the Agatronics 750 and the Hughes Probeye will enhance the ability of fire fighters to survey fire lines and will minimize the need for postburn patrols. The use of these scanners in fire control should increase as they are refined and as fire staff become more accustomed to their operation. They should become standard suppression tools at most fires in the province.

The use of airborne infrared line scanners will probably continue on a very limited basis until suitable units are more affordable. Line scanning devices have potential, particularly in fire detection programs, for assisting staff in detecting fires in their early stages.

Fire managers should check new line-scanning products for more sensitive but less costly devices so that they can integrate airborne line scanning devices into fire operations.

Satellite imagery is just beginning to provide fire managers with usable and readily available products. These products are of marginal quality at present but the potential of satellite imagery is great, particularly for general fuel mapping. The benefits of satellite imagery will depend largely on the availability of data from future satellites and on processing techniques such as enhancement digitization and classification. Fire staff will continue to test new products as they become available. Future improvements in fire management will therefore be dependent to a large degree upon technological advances in the remote sensing field.

LITERATURE CITED

Anon. 1964. Firetech airborne pad-mounted infrared forest fire detection system. DeHavilland Aircraft Co. of Canada Ltd., Inf. Rep. 6 p.

Anon. 1965. Firemapper airborne infrared forest fire detection and mapping system. Computer Devices of Canada Ltd., Descr. Note. 7 p.

Anon. 1979. The intertech real-time firemapper 1978 operational report. Intertech Remote Sensing Ltd., Inf. Rep. 24 p.

Astley, E.R. 1976. The photo mosaic unit. Ont. Min. Nat. Resour., Inf. Rep. 17 p.

Astley, E.R. and Tworzyanski, T.J. 1974. Far infrared heat scanner operations during the 1974 fire campaign in northwestern Ontario. Ont. Min. Nat. Resour., Inf. Rep. 29 p.

Kourtz, P.H. 1977. An application of LANDSAT digital technology to forest fire fuel type mapping. p. 1111-1115 *in* Proc. 11th Internatl. Symp. on Remote Sensing of the Environ., Ann Arbor, Mich.

Myllynen, L. 1977. Probeye infrared viewer evaluation project. Ont. Min. Nat. Resour., Inf. Rep. 20 p.

Wilson, R.A., Hirsch, S.N., Madden, F.H., and Losensky, B.J. 1971. Airborne infrared forest fire detection system: final report. USDA For. Serv., Intermount. For. Range Exp. Stn., Res. Pap. INT-93. 99 p.

Zsilinszky, V.G. and Graham, C.W. 1976. Instruction manual of supplementary aerial photography. Ont. Min. Nat. Resour. 71 p.

SOME APPLICATIONS OF THERMOGRAPHY TO FOREST MANAGEMENT

G. Lawrence
Ontario Centre for Remote Sensing
Ontario Ministry of Natural Resources
Toronto, Ontario

Thermography can be used to show distribution of night temperatures across forest cutovers, thereby permitting mapping of frost pockets and classification of the thermal properties of the cutovers. Differences in temperature between individual trees and entire stands must be studied to determine the potential of thermography for use in forest management.

La thermographie peut servir à montrer la distribution des températures nocturnes à travers les forêts coupées à blanc, permettant ainsi le relevé cartographique des poches de gel et la classification de ces aires coupées à blanc d'après les propriétés thermiques. Il faut étudier les différences de température entre différents arbres et des peuplements entiers pour déterminer les possibilités d'utilisation de la thermographie en gestion forestière.

INTRODUCTION

Thermography is the process of making heat visible. An electronic sensing device is used to record the heat energy coming from a scene. Electronic hardware then transforms this energy into a visible form, generally on a photographic film. The thermal scene can also be seen on a monitor similar to a television set. When the heat detector is placed in an aircraft, large areas of ground can be surveyed at one time.

THERMOGRAPHY

To appreciate fully the potential of thermography, it is important to understand several aspects of heat sensing. With our variable climate, the terms "hot" and "cold" are relative to the season of the year. In summer, for example, a lake may be cold in comparison with the warmth of the season. In fall, the same lake temperature will be warm in comparison with the seasonal cold air masses. These contrasts vary through the year, and may be positive or negative.

In thermography, the energy level recorded at the sensor is not the true temperature of the object. This recorded energy is called the radiant temperature, and is proportional to, but always less than, the true temperature of the object.

The amount of radiant energy reaching the sensor is related to 1) the ability of the surface to give off the energy, and 2) the true temperature of the object. Not all objects have the same ability to radiate energy even though they may have the same true temperature. The greater the ability to give off energy, the higher the radiant temperature that will be recorded. This ability to radiate energy is called "emissivity".

Some of the most important aspects of thermography have to do with the thermal properties of the objects under review. Substances do not heat or cool at the same rate, nor do all materials have the same ability to store thermal energy. For example, copper has a high thermal conductivity: it heats up by transferring heat rapidly throughout its body. However, it has a low heat capacity and cools rapidly once the heat source is removed. Water, on the other hand, requires a long time to heat up but, once it is hot, it can store this energy for a long time.

MISSION PLANNING

The thermal properties of materials provide the basis for the most important question facing those who plan thermography missions: *When does the maximum radiant thermal contrast occur between the object under study and its surrounding environment?* This question, in turn, gives rise to other questions: *What is the best time of year? Does the object under investigation or its surrounding environment have a yearly temperature cycle? Are the cycles synonymous or offset? Should the trees be leafed or leafless? Would a cover of snow mask information or remove background clutter?*

Thermography records energy emitted from an object; therefore, it can be employed with or without daylight. During the day solar heating tends to mask many thermal contrasts. Vegetation, however, reacts to solar heating. Healthy vegetation cools itself through evapotranspiration. Unhealthy vegetation cannot cool itself to the same extent. Also, different types of vegetation transpire at different rates. Under these conditions, temperature contrasts are produced.

In the post-sunset period and during the early evening, features with high thermal conductivity will lose rapidly the heat gained during the day. At this time rock outcrops and similar materials with high thermal conductivity will show as hot spots on the thermographic sensing device. Well into the night materials with high heat capacities will still register as warm, whereas materials with less heat capacity will have cooled by this time.

In the pre-dawn period, solar heating effects are minimal. This is the most stable time in the daily thermal cycle, when emissivity plays a major role in the radiant temperatures sensed.

Before a mission can be undertaken, acceptable climatic conditions must be determined. Air temperatures will affect the temperatures sensed. What is an acceptable temperature range for the proposed mission? Wind can cool or warm surface features. What wind speeds are acceptable?

On clear days, energy radiated from the ground passes unhindered through the atmosphere and is lost to the sky. Clouds prevent this loss: they capture the energy and radiate it back to the ground. Clouds also radiate energy in proportion to their temperature.

These exchanges between the ground and clouds can both help and hinder thermography missions. Each mission must be analyzed and the question "What percentage of cloud cover is acceptable?" must be answered.

Once these basic questions have been answered, thermography can do many things that the human eye is incapable of doing.

FORESTRY APPLICATIONS

Damage to tree seedlings by frost is a problem of major importance in some areas. Most frost damage occurs in the late spring. During the early growing season, the structure and high water content of cells in new terminal shoots renders them particularly susceptible to frost damage.

Frost is created by two different processes. Advective frost occurs when a cold, stable air mass moves into a region affecting a large area. Frost of this nature generally causes uniform, widespread damage. More often, however, frost occurs only in specific localities. Such frost is due to night-time heat transfer processes. The damage done by this frost is particularly common in pockets or low-lying areas with poor air circulation. These frost pockets can be detected by means of aerial thermography.

Conditions are ideal for frost pocket formation on clear, calm nights when the air temperatures are close to freezing. Heat energy stored in the ground is lost to the clear night sky. This causes the ground surface to cool. When air is cooled, its density increases. The dense air is then drawn by gravity into low-lying areas. The pooling of cold air in the bottom of the hollow intensifies ground cooling at the site, and this intensified cooling creates a high frost potential.

Thermography has been used to show the distribution of night temperatures across forest cutovers. Figure 1 consists of a thermograph, a stereogram and a schematic diagram of a cutover in weakly to moderately broken uplands of shallow sand with some exposed bedrock (Ontario Land Inventory Classification). The thermography was done between 05:27 hr and 07:40 hr EST on 19 May, 1978 at a flying altitude of 1 370 m. There was no wind. Scattered high cloud was present.

The stereogram (Fig. 1C) shows a hill sloping to a stream valley. A cutting reserve has been left along the stream course. Temperature measurements were made 10 cm above the ground, down the hill and across the bottom of the depression to the trees.

Figure 1B is a schematic representation of the pocket cross-section. Temperature measurements made at the time of flight and on two other mornings, November 1 and 3 (under similar weather conditions), are shown on the schematic. A significant drop in temperature was recorded between the top and bottom of the hill on all three occasions. The thermograph (Fig. 1A) shows the extent of this pocket (the black or "coldest" tone).

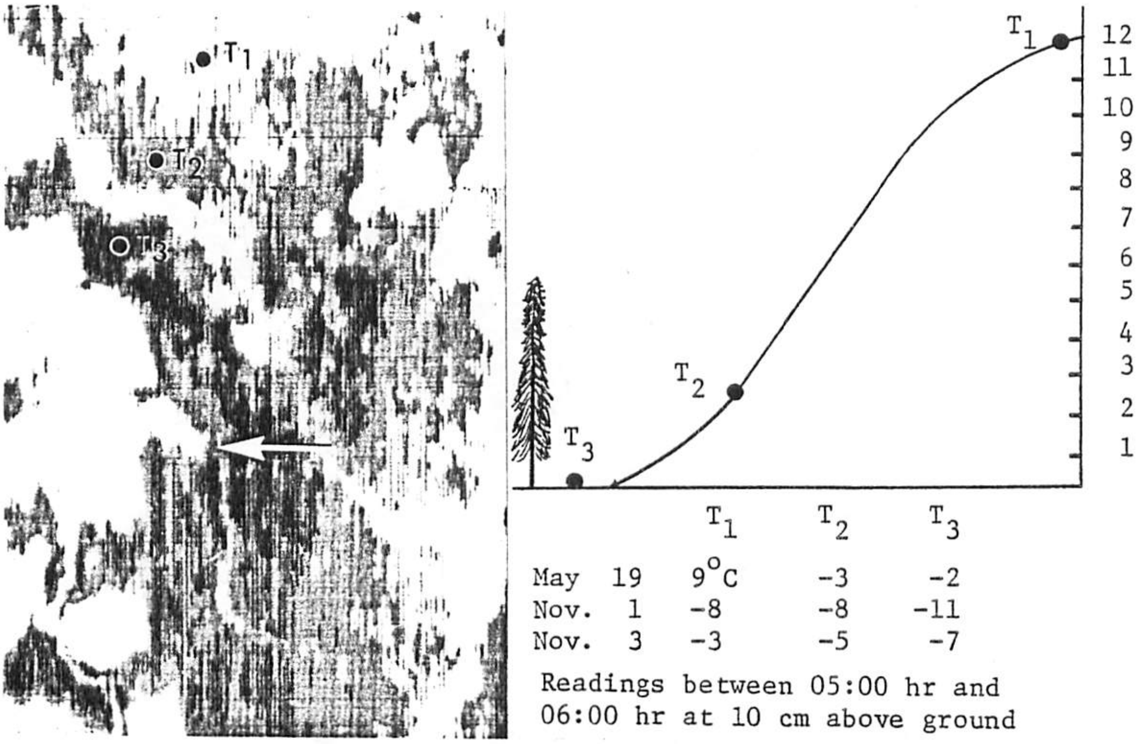
THE THERMAL NATURE OF CUTOVERS

Where treatment of individual frost pockets, such as planting frost-hardy tree species, may not be economical, classifying the thermal nature of individual cutovers may be beneficial. Thermography provides a measuring stick for comparing the thermal properties of widely separated cutovers.

Figure 2 shows several cutovers located in close proximity. The thermograph is processed to show the overall thermal character of the cutovers. Note that Cutover A is darker on the thermograph, and therefore cooler than Cutover B. The thermal properties between cutovers will vary with 1) the texture of the soils, as finer grained soils generally conduct heat energy better than coarse textured soils; 2) soil moisture, as water increases heat capacity; 3) terrain, as it affects the local air movements; and 4) local climate, which may vary over short distances.

The cooler the cutover, the more susceptible it will be to frost damage when the air temperature is cold enough.

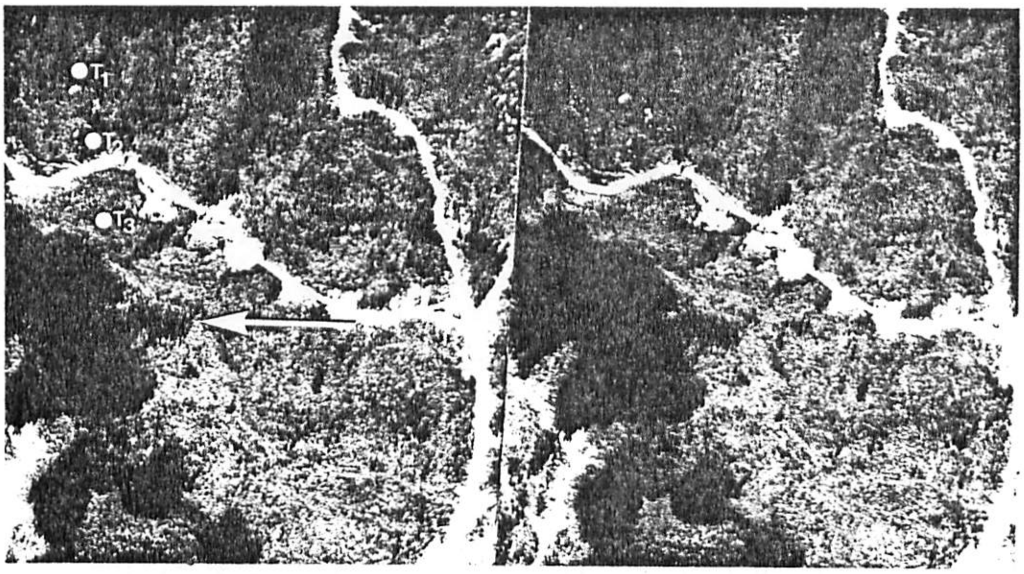
In topographically flat areas, the risk of extensive frost damage is much greater than in more rugged terrain. On flat clearcut areas, cold air that has collected at the ground surface does not move



	T_1	T_2	T_3
May 19	9°C	-3	-2
Nov. 1	-8	-8	-11
Nov. 3	-3	-5	-7

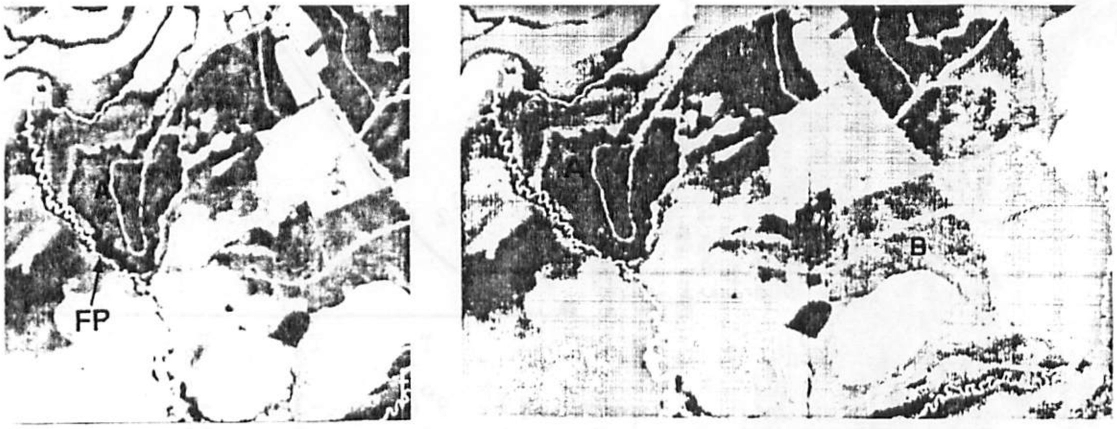
Readings between 05:00 hr and 06:00 hr at 10 cm above ground

A: Thermograph B: Schematic presentation

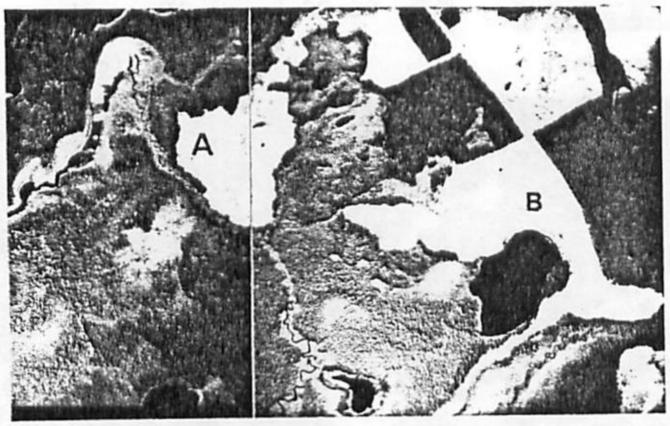


C: Airphoto stereogram. Temperature measurements, at time of thermography flight May 19, and on two other occasions with similar microclimate conditions, verify cold air pooling at this site. The skies were clear and there was no wind each time. The black tone, or coldest area on the thermograph, outlines the frost pocket. Note that the trees are representing the white or warmest tone. The arrows point to the same feature on both the airphoto and the thermograph.

Fig. 1. Temperature profile across a frost pocket.



Detailed thermograph General temperature thermograph



Aerial photograph

Fig. 2. The detailed thermograph shows the thermal distinctions within a cutover. A potential frost pocket is seen at FP. The general thermograph looks at broad temperature variations. Cutover "A" is represented by the cold, dark tones. This contrasts with the warmer lighter-toned cutover at "B". Note that the stands of trees are warmer than the cutovers, and the lakes and river are the warmest features.

into hollows. Instead, the whole area becomes one large frost pocket. To lessen the impact of frost, a form of strip cutting may be required. The energy interaction between standing strips of trees and clear-cut strips will lessen the frost potential.

Energy radiates equally in all directions much like light from a light bulb. The closer an object is moved to the light, the larger the shadow behind the object. The closer a tree is to a particular piece of ground, the greater the interaction between the tree and the ground. As with the light/shadow effect, the tree acts as a shield or block, preventing the ground radiation from reaching the sky. At the same time, energy from the tree interacts with the ground. The reduced view of the sky and the energy exchanges with the trees reduce the frost potential of the site. The amount of protection provided by the trees will depend on their height and their distance from the site requiring protection. These factors will govern the cut-strip width.

Thermography has shown that the practice of leaving reserves along river courses may increase the frost potential of an area.

Cold air does not pass through stands of trees readily. Where cold air moves down a slope and meets a reserve, an artificial frost pocket is created. Thermography can show where these pockets are located. The solution to this problem may be as simple as cutting a clear path from the pocket to the stream, thereby permitting the cold air to drain away.

Thermography has also shown that scarification affects the thermal property of a cutover. The scarification process loosens and mixes the top layer of organic material and mineral soil. In the process the thermal conductance of the surface is reduced. Less heat can be transferred to the ground for storage, and less can be transferred from the ground to the surface to compensate for night cooling. Scarification can then increase the potential for local frost. In coarse soils where the thermal conductance is already low, scarification may create a frost hazard.

OTHER THERMAL FEATURES OF THE FOREST

The general thermal performance of trees has not yet been determined by means of thermography. On winter thermography, trees always appear warmer than the surrounding ground, and conifers always appear warmer than the leafless deciduous species. A spruce tree 1.5 m tall with a branch diameter of 1 m is thermally distinguishable from an altitude of 600 m above the ground.

Figure 3 is a graph of the thermal performance of two tree species over a 36-hr period in the winter. A white birch tree with a DBH of 38 cm and a white pine with a DBH of 49.5 cm were cored, and a

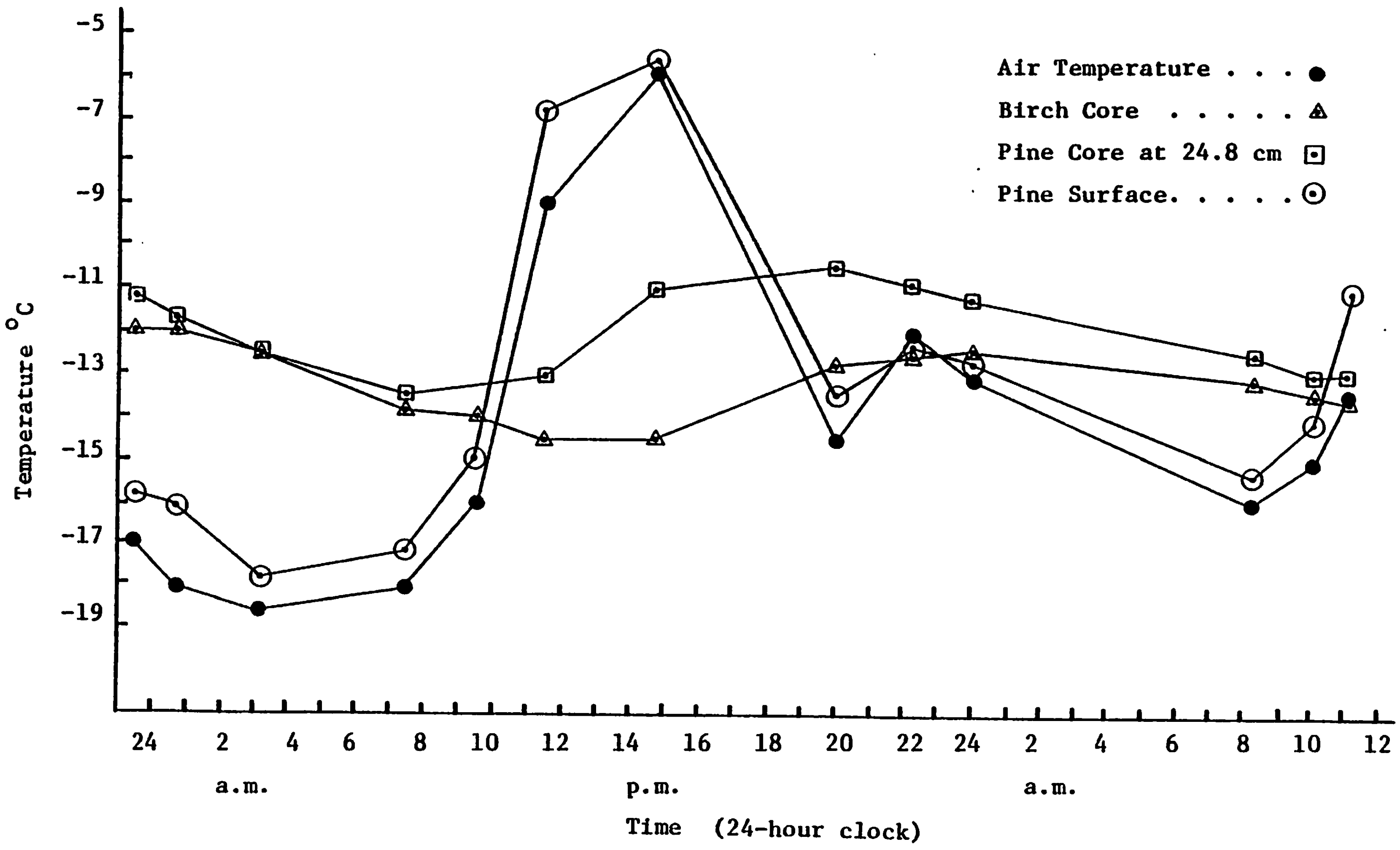


Fig. 3. Thirty-six hour temperature cycle of two trees in winter.

temperature probe was placed at the centre of each tree at breast height. A third probe was used to record the surface temperature of the pine, while a fourth recorded air temperature. Each tree was situated in the open, not in a forest stand. The skies were clear throughout the 36-hr period.

The graph shows that temperature fluctuations within pine are much greater than those within birch. During the day, pine warms up much faster and to a greater degree than does birch. At night, both trees cool to the same temperature. These fluctuations most likely occur because the cover of needles captures more solar heat for the pine. The high solar reflectance of white birch bark reduces solar input to the birch. This creates a thermal contrast between the two trees.

The graph also shows that at night, the tree core never gets as cold as the outside air. Energy, either stored during the day or conducted up from the ground at night, provides the basis for a thermal contrast between air and tree at night. This is probably one reason that the surface of the pine tree is always warmer than the air temperature.

Figure 4 is a thermograph of a mixed species woodlot in southern Ontario. The thermograph was done on a cold winter night (air temperature -18°C) from an altitude of 600 m. Although it was not done specifically for forestry study, the thermograph shows temperature differences across the woodlot. Thermal patterns appear to be related to two features: stand density contributes to the warm outline at 'C' on Figure 4, while individual species differences are indicated by the many warm points across the image, some of which are identified by the letter 'D'.

If live trees and dead trees have different thermal signatures, winter thermography should be able to designate trees for salvage after a disease or insect outbreak.

In summer the forest canopy shows much thermal variation. As a reaction to solar heating, healthy vegetation cools itself through evapotranspiration. Evaporation of moisture from leaves reduces leaf temperature. Stressed vegetation does not transpire freely and is not able to cool itself as well as healthy vegetation; hence it exhibits a general warming tendency. Thermography may be able to exploit this feature to assess damage done to trees by disease or insects.

Thermography may also be useful in species identification. All plants are not identical in structure, nor do they possess similar thermal properties. Where conventional interpretation of plant species is difficult, thermography may be the most useful tool.

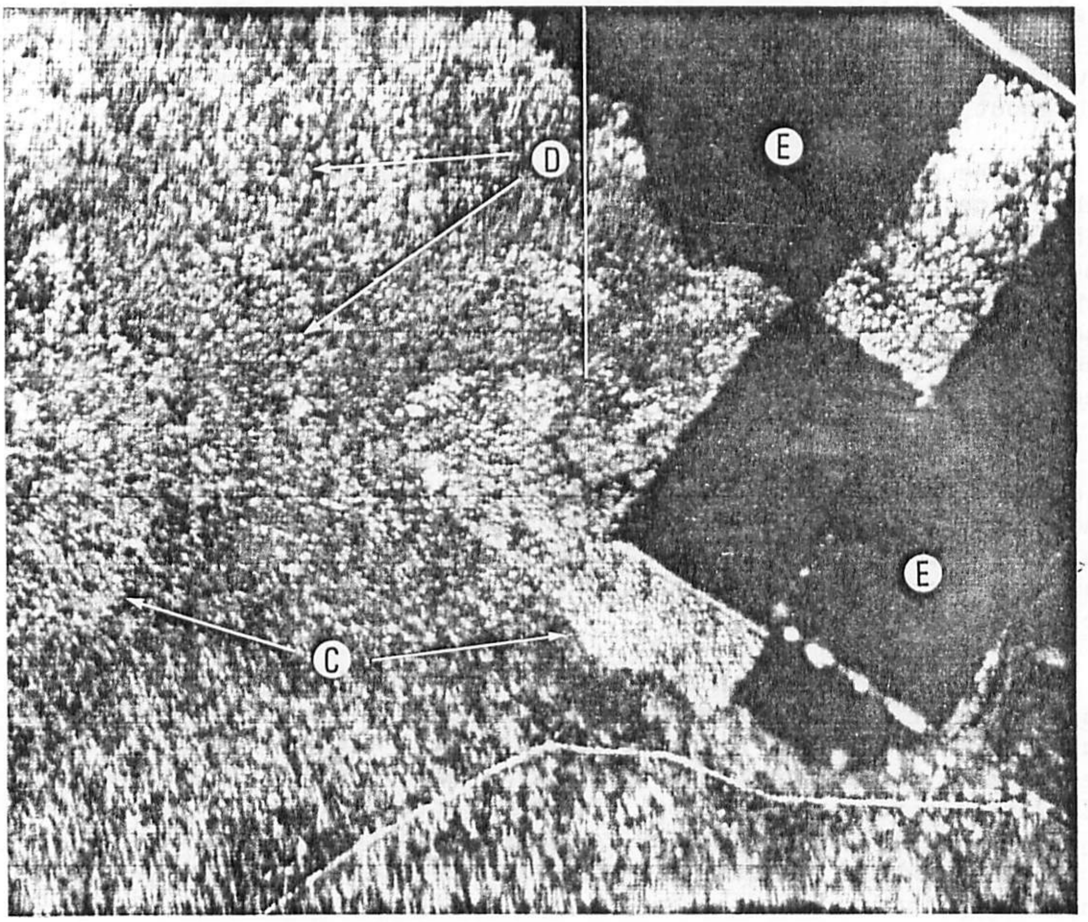


Fig. 4. Thermal differences exist between individual trees and groups of trees. On this thermograph, individual warm (white) trees are shown by the letter "D". Warmer groups or stands of trees are seen at "C". The thermograph was acquired at night in the winter, air temperature -18°C. The snow-covered field "E" is cold and dark in tone, compared with the trees.

CONCLUSION

Thermography has not yet been fully exploited in forestry studies. Initial studies indicate that thermography may be useful in species identification, state-of-health assessment, microclimate and the thermal properties of the location with respect to its surroundings, and forest cutting practice. More work is needed at different times of the day and year to discover the potential of thermography for use in forest management.

INTEGRATION OF REMOTE SENSING TECHNOLOGY WITH ASSESSMENT OF CONIFEROUS REGENERATION SUCCESS[1]

N.L. Goba
Forester

J.L.A. Narraway
Senior Research Technician, Forestry

and

S. Pala
Supervisor, Research and Planning

Ontario Centre for Remote Sensing
Ontario Ministry of Natural Resources
Toronto, Ontario

Surveys to assess the success of forest regeneration have been given a new perspective through the use of small format, color infrared aerial photography. The technique is economical and provides greater precision and accuracy than were previously possible. This paper outlines briefly the specifications for aerial photographic coverage, describes the assessment methodology developed, and presents a comparison of airphoto and field assessment results.

On a donné une perspective nouvelle aux relevés effectués pour évaluer le succès de la régénération des forêts par l'emploi de photographie aérienne infrarouge en couleur, de petit format. Il s'agit d'une technique économique qui fournit plus de précision et d'exactitude qu'on ne pouvait obtenir antérieurement. Cet article met brièvement en évidence les spécifications du champ d'application de la photographie aérienne, il décrit la méthodologie d'évaluation mise au point et offre une comparaison entre les photographies aériennes et les résultats obtenus après évaluation sur le terrain.

---

[1] This paper is based on the following report: ANON. 1978. A survey methodology for conifer regeneration success using supplemental aerial photography. Ont. Min. Nat. Resour., Ont. Centre for Remote Sensing, Toronto, Ont. 72 p.

INTRODUCTION

The expansion of forest regeneration programs in Ontario has prompted the search for a more rapid, economical, yet sufficiently precise method of assessing regeneration success. The Ontario Centre for Remote Sensing (OCRS) and the Thunder Bay Regional Office of the Ontario Ministry of Natural Resources (OMNR) undertook a joint program to develop an assessment technique utilizing aerial photography to expedite the process. Design criteria for the development of an effective assessment methodology were as follows:

a) that the methodology complement the conventional fifth-year ground assessment survey (normally carried out 5 to 7 years after establishment) and meet existing survey requirements (Anon. 1973)

b) that it be able to assess "established" coniferous regeneration (in spruce >.5 m; in jack pine >.8 m)

c) that it use large-scale photography to provide additional information on regeneration success such as estimation of stocking density (trees/hectare)

d) that it stratify the treated areas accurately on the basis of relative density, stocking, height, age and physiographic features

e) that it use aerial survey data to provide effective input to subsequent management planning

f) that, for reasons of economy, it limit field sampling to the minimum required to achieve optimum accuracy.

A program was undertaken to design a package of aerial photography data that could be obtained economically from a single, operationally efficient altitude. Three transparent templates were designed as interpretive aids to match the scales at which we were operating and to facilitate the assessment of "established" regeneration.

INVESTIGATION SITES

Site 1 (Hoof Lake) and Site 2 (Mooseland Lake) are located in the Thunder Bay District in northwestern Ontario (Fig. 1). They were chosen by OMNR regional timber staff for the variety of stocking conditions they represent.

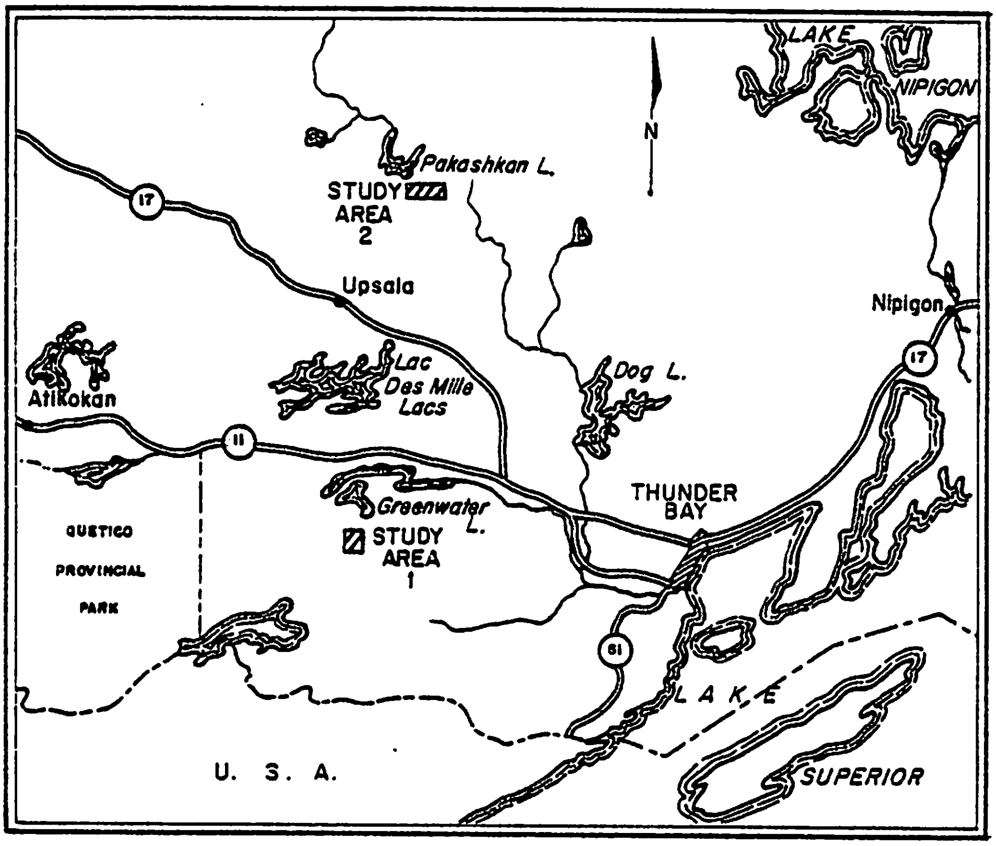


Fig. 1. Location of investigation sites in northwestern Ontario (scale: 1:2 000 000).

AERIAL PHOTOGRAPHY

Aerial photographs were taken from a twin-engined, light aircraft which flew over the two study sites at a single altitude (900 m[2] above ground level [AGL]). The craft was equipped with three 70 mm Hasselblad 500 E/L cameras fitted with 40 mm, 100 mm and 250 mm lenses, respectively, to provide coverage at scales of 1:22 900, 1:9 140 and 1:3 660 simultaneously. The cameras were loaded with Kodak Aerographic Infrared (AIR) 2443 film, exposed through a combination of Wratten #12 and CC10B filters. The exposed film was processed to positive transparency for direct interpretation, while relevant frames were produced as two- and four-times enlargements for mosaics and field sampling, respectively.

---

[2] Altitude rounded to nearest 100 m.

Factors found to affect the quality and success of the survey operation are discussed below.

Photo Season

The photo season, i.e., the time of year when conditions are best for obtaining aerial photographs for use in assessing regeneration success, covers the months of April and May. This coincides with the period between snow melt and deciduous leaf flush during which the obscuring effect of deciduous foliage is minimized and the contrast in infrared reflectance between coniferous regeneration and background material, i.e., slash, duff and exposed soil, is maximized. The color infrared aerial photographs for sites 1 and 2 were obtained on May 16 and 17, 1978, respectively.

Exposure

Extensive testing has shown that proper exposure of AIR film is a critical factor affecting color quality and, consequently, assessment accuracy. In this study proper exposure was obtained by using a well calibrated WILD/OFP PEM-1 light meter with a wide angle of acceptance (60°). However, it is thought that a light meter with a narrow angle of acceptance (30°), if available, would produce more reliable and consistent exposure results (Anon. 1978).

In addition, Fleming (1976) suggests that the infrared sensitivity of film emulsion can be enhanced by the use of a film/filter combination to achieve an "IR-balance" of 35. In this particular study, the emulsion batch and altitude combination used required a Wratten #12 and a CC10 Blue filter to achieve the proper balance. This combination attenuates the visible portion of the spectrum, allowing almost unimpeded transmission of the near infrared, and results in a properly enhanced infrared record. Such enhancement greatly improves color quality and the interpreter's ability to detect conifer regeneration.

Photo Scales

Each of the three scales of aerial photography illustrated in Figure 2 (a, b and c) was selected for a specific purpose on the basis of design criteria and equipment constraints. To meet the need for both detail and overview, a simultaneous multi-scale, multi-camera aerial photography operation was developed.

Equipment constraints necessitated an operational altitude of 900 m AGL. At this altitude the maximum cycling rate of the Hasselblad camera system is attained with the 250 mm lens; this permits the largest scale of aerial photography possible with 60% forward overlap for stereoscopic viewing. Exceeding these limits could result in inconsistent

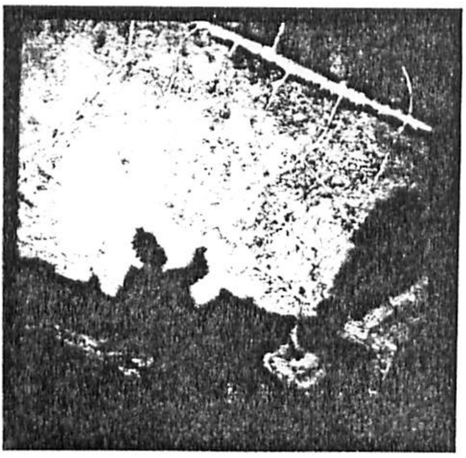


Fig. 2a

Sample SAP of study area 2. Photo scale 1:22 900 obtained with 40 mm lens from 900 m AGL. This scale used for synoptic overview, mosaic and regeneration stratification.

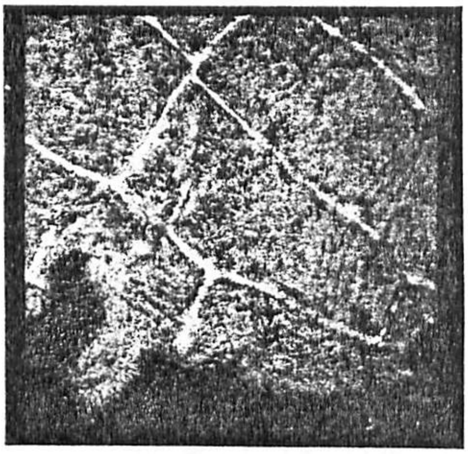


Fig. 2b

Sample SAP of study area 2. Photo scale 1:9 140 obtained with 100 mm lens from 900 m AGL. This scale used for aerial stocking estimation.

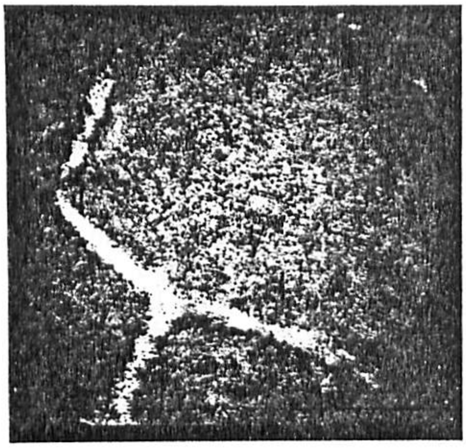


Fig. 2c

Sample SAP of study area 2. Photo scale 1:3 660 obtained with 250 mm lens from 900 m AGL. This scale used for regeneration density estimation.

overlaps and uncertain results. Selection of the two smaller scales was contingent on establishment of the largest scale that was sufficient for assessment requirements.

ASSESSMENT METHODOLOGY

Stratification of Regeneration

A more detailed and precise evaluation of regeneration success was achieved by stratifying the area into smaller stands of apparent stocking homogeneity. Further interpretation verified the relative success of regeneration in each type and clearly identified those areas requiring further silvicultural treatment.

A mosaic for stratification was prepared using two-times enlargements of aerial photographs obtained with a 40 mm lens from 900 m above ground. A transparent overlay on which the different levels of stocking were delineated was placed on the mounted mosaic.

Stratification of the regenerating area was based on 1) year of establishment, 2) type of establishment (seeded, planted, etc.), 3) silvicultural treatment (scarification), 4) species composition, and most important, 5) relative stocking and density homogeneity.

Physical features such as roads, residual stands, rivers and lakes also constituted type boundaries. Much of the above information can be identified or inferred from aerial photographs. However, year of establishment and species composition are best verified from district records of regeneration establishment and survival. Once stratified, the types were numbered and their areas were measured. Stocking and density estimates were then interpreted directly from the aerial photographs using templates designed for the purpose.

Aerial Stocking Template

The transparent template in Figure 3 was prepared for interpretation of stocking at a scale of 1:9 140. It consists of one hundred 0.0004 ha (1 milacre)[3] plots spaced 20 m apart in a 200 m square grid. The grid was placed randomly on an original transparency frame containing a portion of the type being assessed, and all the stocked plots were tallied with the aid of a four-power stereoscope. A plot was considered stocked if any identifiable regeneration was located within the plot boundary. Generally, a 100-plot sample per type sufficed, but in larger types (over 100 ha), two or more 100-plot samples were taken to ensure stocking consistency. Any major discrepancy should be restratified.

---

[3] Field work was carried out in English units.

Aerial Density Template

A second transparent template was designed for stand density estimation using 1:3 660 scale aerial photographs (Fig. 4). This scale is preferred but the template includes four other scales to allow for fluctuations in above-ground altitude, if significant (>30 m). The template was placed on the diapositive film to match the ground survey plot precisely and all identifiable trees within the plot were counted with the aid of a stereoscope. Under operational conditions, however, the sample would be taken at random. A factor of 10 was applied to obtain a density estimate (no. of trees per 0.4 ha).

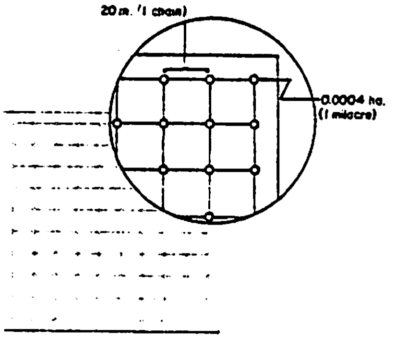


Fig. 3. Example of template for airphoto stocking estimates. Enlargement shows design detail. (approx. scale 1:9 140)

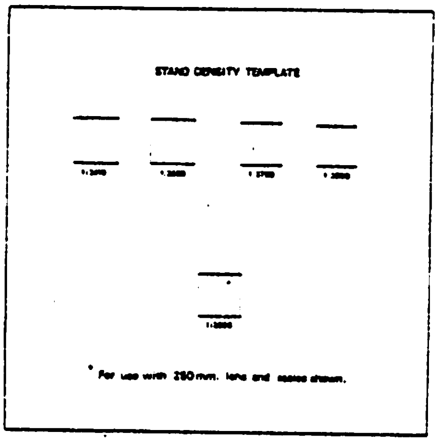


Fig. 4. Example of template for airphoto density estimates. (to scale, 1:3 660)

Comparator Design

A third template, which is in the process of being designed, will provide a subjective estimate of both stocking and density based on computer-simulated regeneration distribution models. The data for the computer models are not yet complete and further design modifications are necessary. However, the example in Figure 5 gives some idea of the design of the proposed comparator.

Field Assessment

Field surveys of regeneration stocking and density were carried out to determine the level of accuracy of the aerial estimates. The stocking survey consisted of varying numbers of 0.0004 ha plot pairs spaced at 20 or 40 m intervals, depending on type size, along a cruise line of specific bearing and point of origin. All plots containing desirable species, regardless of size, were tallied as stocked. Other information recorded included tree height and total number of trees per plot. The density survey consisted in laying out a 0.04 ha plot (20 m square) and subdividing the plot into 25 subunits (5 x 5). All desirable species in each subplot were mapped and tallied by height class. The locations of stocking and density ground sample plots were marked on the mosaics.

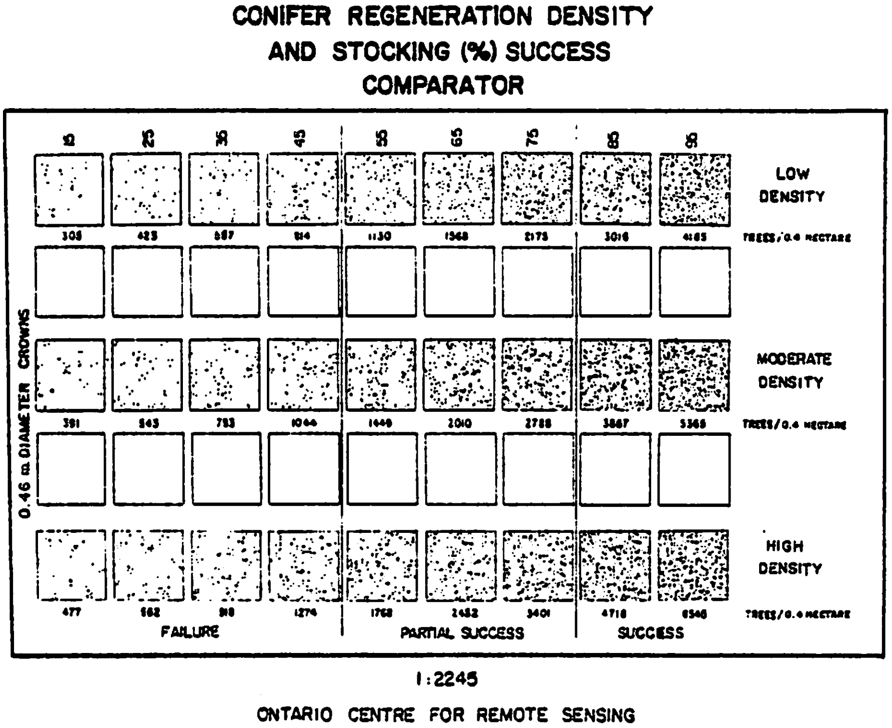


Fig. 5. Example of computer-simulated regeneration stocking and density comparator template design. (not to scale)

RESULTS

Density Estimates

Airphoto density estimates made by three interpreters were compared with field estimates (Fig. 6). The major inference to be drawn from the graph is that trees 0.3-0.6 m high could be identified with considerable consistency. Although the density was generally underestimated it was evident that the denser the stands, the greater the underestimation (e.g., plot H5-3, Fig. 6). Here, the suppressed trees

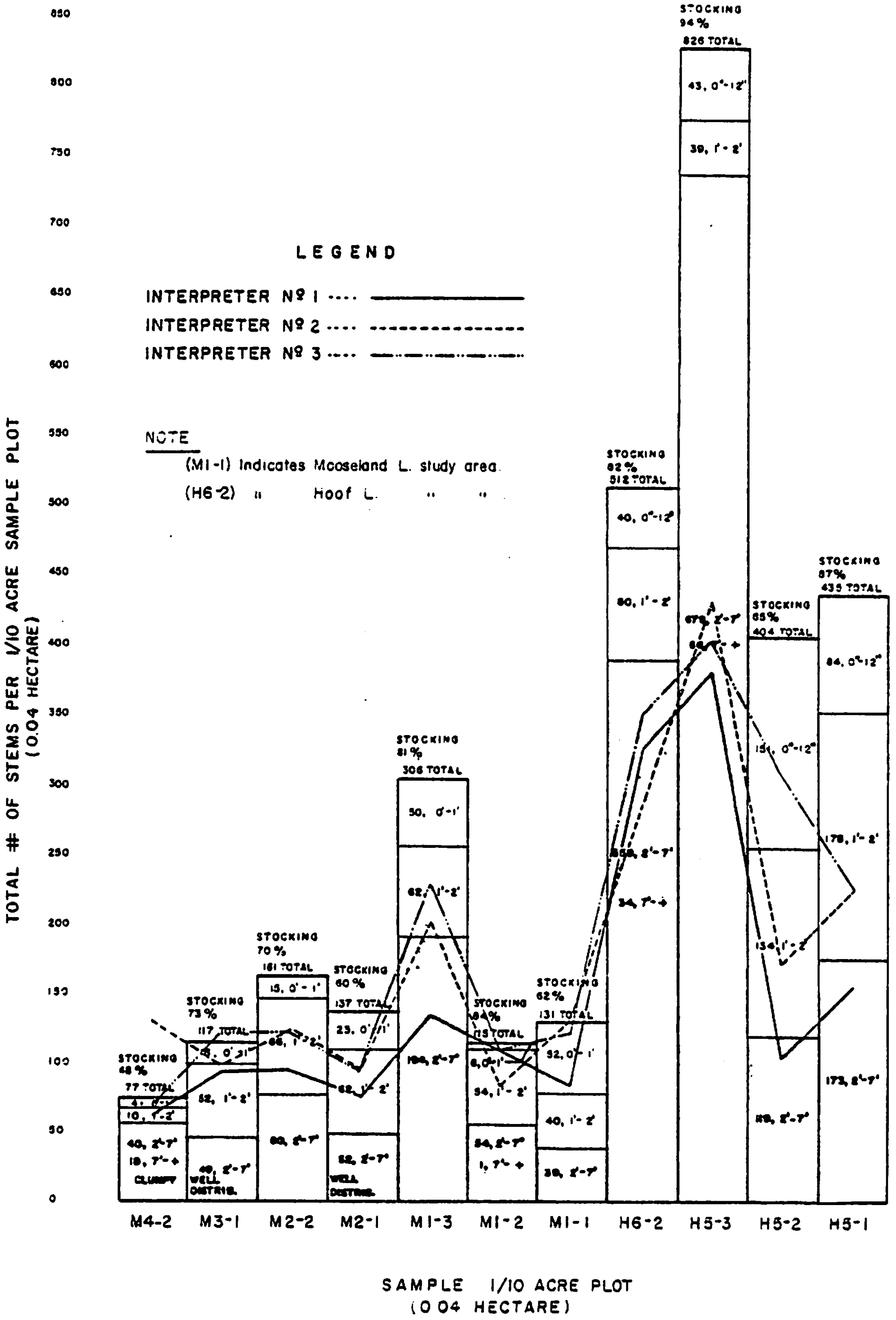


Fig. 6. Graphs and histogram showing comparative results of airphoto and field density estimates.

were obscured by the dominant and codominant crowns and, therefore, were not visible to the interpreter. The identification of individual crowns was very difficult because of the cluster habit of jack pine (*Pinus banksiana* L.) under such conditions. In more open stands, because of the dense branching habit of spruce (*Picea* spp.), 0.3 m trees were clearly distinguishable. In open stands where trees were tall, care had to be taken not to interpret a single tall tree as a cluster of smaller trees (e.g., plot M4-2, Fig. 6). The data in Figure 6 also suggest that the interpreter's familiarity with growth characteristics and distribution patterns greatly improved the accuracy of aerial density estimation, as Interpreter No. 1 had the least exposure to regeneration field conditions, while Interpreter No. 3 had the most. This is reflected by generally higher estimates, even though the variation in estimates was not considerable.

Stocking Estimates

A comparison between airphoto and field stocking estimates is given in Table 1. When a comparison was made, under linear regression, of airphoto estimates and actual field estimates, virtually no correlation was found. The field estimates included all plots stocked with trees of any size. Since trees smaller than 0.6 m, and outside the guidelines, could not be identified even at the scale of 1:3 660, plots stocked only with these trees were removed from the field estimate. This modification so improved the correlation between the two estimates that the regression indicated a correlation coefficient of $r = 0.8$. This result suggested that the specific stocking percentage of visible growth was estimated with considerable precision.

An accuracy of 86% was achieved in the interpretation of regeneration success categories (Anon. 1973). The following confusion matrix illustrates the degree of success achieved in identifying the categories of regeneration success on the basis of minimum stocking standards for jack pine and spruce (i.e., 2 500 trees per ha at 2 m spacing).

		Aerial stocking estimates		
		Success	Partial success	Failure
Modified field stocking estimates	Success	3	0	0
	Partial success	2	6	0
	Failure	0	0	3

Table 1. Comparison of airphoto and field stocking estimates.

					Stocking estimates (%)					
Study area	Type no.	Area (ha)	Avg ht (m)	Density[a]	Field (actual)	No. of plots	Field (mod.)	No. of plots	Photo	No. of plots
Hoof Lake	13	67+	1.4	1530	56	66	57	14	72	200
	15	7	.9	2480	54	50	42	36	61	100
	17	141	.9	3174	73	86	59	70	52	100
	23	62	1.5	2857	63	70	61	70	68	100
	32	106+	.6	3560	75	116	48	116	41	200
Mooseland Lake	5	66	.9	1420	54	50	36	50	40	100
	10	15	.6	3074	80	54	38	42	39	200
	32	30	.9	1482	76	116	55	80	50	400
	33	42	1.5	1819	69	94	46	58	62	200
	45	16	1.4	1702	54	84	47	32	73	200
	46	17	1.2	2222	78	18	78	18	88	100
	51	54+	.9	2179	56	134	28	82	35	200
	52	153	2.1	3245	73	192	72	192	78	600
	60	-	1.5	1576	54	26	54	26	60	300

[a] Stems/0.4 ha

With respect to the accuracy of stocking estimation, it was observed that the taller and larger the crown, the greater the tendency to overestimate stocking, because large crowns infringed on otherwise unstocked plots. The greater the portion of small trees (<0.6 m), the greater the tendency to underestimate actual stocking because, at a scale of 1:3 660, the smallest trees could not be detected in plots which a ground survey would tally as stocked. These small seedlings should be classed only as "conditional" stocking, not "established" stocking as in field assessment.

CONCLUSIONS

For the forest manager, the most important advantage of applying remote sensing technology to regeneration success surveys is that, for the first time, he can obtain a clear picture of the regenerated area and of regeneration conditions in the area.

Other advantages of this survey technique are as follows:

1) it provides greater precision in stratification, which permits accurate regeneration surveys

2) it provides more precise forest typing for management plan revision

3) it permits inaccessible areas to be surveyed

4) it requires minimum field sampling to achieve maximum assessment accuracy because of more precise stratification

5) it can accommodate the sampling method most suited to the operation (e.g., sequential stocked quadrat tally)

6) it can be used in identifying damage due to insects, disease or frost

7) it permits assessment schedules to be met despite natural setbacks.

With the availability of such detailed data and an efficient assessment technique, a forest manager can make a rapid, precise, accurate and economical evaluation of regeneration success, and can plan further, more effective treatment programs.

LITERATURE CITED

Anon. 1973. Regeneration survey instructions. Ont. Min. Nat. Resour., For. Manage. Br., Toronto, Ont. 25 p.

Anon. 1978. The procurement and use of 35 mm aerochrome infrared film. Ont. Min. Nat. Resour., Ont. Centre for Remote Sensing, Toronto, Ont. (internal report).

Fleming, J. 1976. The virtues of necessity: exploiting the variability of aerochrome infrared film. Dep. Energy, Mines Resour., Can. Centre for Remote Sensing, Ottawa, Ont. 15 p.

Discussion

In response to a query concerning the implementation of a program to evaluate forest regeneration using the technique described, there was considerable comment about whether the operation should be handled by OCRS, the private sector, or internally by OMNR. The OCRS strategy is to complete the development of the technique and then to transfer this new technology to others to implement. Concern was expressed that this is a specialized technology and would be difficult to contract out to the private sector. A suggestion was made that the supplementary photography be handled internally by OMNR at the regional level with aircraft and trained specialists located at regional headquarters. OMNR field staff commented that, before they could get excited about the technique, it would have to be operationally viable as proven by field trials. Some skepticism was expressed because the technique does not permit differentiation among species.

SESSION V

Where Do We Go From Here?

Chairman: K.A. Armson
Special Advisor
Forest Regeneration
Ontario Ministry of Natural Resources
Toronto, Ontario

COST EFFECTIVENESS OF REMOTE SENSING

T.T. Alföldi
Applications Division
Canada Centre for Remote Sensing
Ottawa, Ontario

Remote sensing is ideally suited for environmental management applications. No other technique can provide synoptic and repetitive coverage of large areas in such a cost-effective manner. Ontario's forest managers require timely environmental information on a province-wide basis to deal efficiently with a natural resource that is becoming increasingly popular. The institutional, technical and educational bases for capitalizing on remote sensing applications exist in Canada. What remains is to demonstrate to potential users those data types and analysis techniques which are indisputably cost-effective, and to assure them that remote sensing technology is continuously being improved.

La télédétection est un instrument idéal aux applications de gestion de l'environnement. Nulle autre technique ne peut fournir des renseignements synoptiques et répétitifs sur de grandes superficies à un coût moindre. Les gestionnaires forestiers de l'Ontario ont besoin de renseignements environnementaux synchronisés sur une base à la grandeur de la province afin de gérer efficacement une ressource naturelle qui augmente sans cesse en popularité. Il existe au Canada des bases institutionnelles, techniques et éducationnelles pour capitaliser sur les applications de la télédétection. Il reste à démontrer aux usagers possibles les techniques d'analyse et les types de données qui sont indiscutablement efficaces à un coût relativement bas et à les assurer que la technologie de télédétection s'améliore continuellement.

INTRODUCTION

Remote sensing has enjoyed wide popularity in Canada over the past decade. Initially, much of the interest was due to the introduction of novel data sources that provided a new perspective on the environment. Innovations in both analogue and digital image analysis also attracted scientists to this field. In the last five years the use of remote sensing technology has increased even further but for a different reason. More and more practical applications are being developed which provide useful and timely information about the environment in an economical manner.

There is definitely a need for this type of data. The current emphasis in Canadian forestry is on "managing" forests instead of merely "harvesting". Forests are a renewable resource, however, and planning is essential for their optimum exploitation. A recurring theme in a recent comprehensive report on forest management in Canada (Reed and Associates Ltd. 1978) is the general lack of intensive forest management. It may be surmised that less than ideal management practices are due mainly to the lack of appropriate data on which decisions must be based. This hypothesis is reinforced by the simple fact that in order to monitor Canada's immense forests effectively by means other than remote sensing would be impossibly expensive; costs would exceed the value of the commodity being managed.

Large scale black and white aerial photographs were the first source of remotely sensed data to provide useful, cost-effective information for forest inventory. In Ontario, such photographs were collected on a regular basis as early as 1946 (Zsilinszky 1964, Anon. 1978). Smaller scale (higher altitude) photos from more informative film types (e.g., normal color, false color infrared) are also being used operationally in forestry (Cihlar and Rubec 1979a), and satellite imagery, predominantly LANDSAT Multispectral Scanner (MSS) imagery, is finding numerous practical applications in forestry and other earth sciences. The resource manager is advised to collect his environmental data from the highest practical altitude, since the cost of environmental monitoring is inversely proportional to the altitude from which the data are acquired. This is true for aerial photography because higher altitude means more coverage per photograph, and results in lower photographic costs and faster interpretation. With satellite imagery, the aerial coverage per image is extended even further and since many users are subsidizing the same mission, individual costs can be reduced.

RATIONALE FOR THE USE OF REMOTE SENSING

The underlying question being asked at this symposium is, "Why use remote sensing for resource management?" Many responses are possible but the all-encompassing and final answer is, "Because it's cost-effective!" Resource specialists find the use of remote sensing technology economical because of the nature and availability of remote sensing products, as detailed below.

REMOTE SENSING DATA CHARACTERISTICS

Whether aerial or satellite imagery is used, the data are objective and unbiased. This is essential in a discipline such as forestry in which more conventional data-gathering techniques rely on visual identification and manual mensuration, with their accompanying subjectivity and irrecoverable error. The distortions and errors in remotely sensed imagery are in principle calculable and hence correctable. Any information drawn from the images may be checked or reinterpreted *from the original*. In addition, the data set may be reanalyzed at a later date when a different type of information is required or new analysis techniques become available. Thus, one may realize substantial savings by using the same data set for multiple purposes instead of resorting to repeated fieldwork *in situ*.

The synoptic nature of remote sensing imagery is particularly useful for environmental monitoring. Large areas may be mapped in a very short time and comparisons may be made with similar inventories taken in a different season or year for the purpose of evaluating environmental dynamics. If more conventional techniques are used, either the areal coverage must be severely limited or a time-skewness must be introduced, and the total data set becomes very awkward to handle.

One of the basic characteristics of satellite imagery which often goes unrecognized is its repetitive coverage. Each cycle of data acquisition is provided automatically and predictably without any effort on the part of the user. This should be contrasted with the complex and tedious logistical preparations necessary for a typical field excursion. The user of satellite imagery merely has to choose images with suitably cloud-free coverage of the areas of interest in the season and year required. The traditional problem of data scarcity is often reversed when satellite imagery is used. For Ontario alone 10,000 LANDSAT photographs are now available (Table 1).

Table 1. LANDSAT photographic coverage for Ontario.

Satellite	Lifetime of satellite	Number of photos
LANDSAT 1	26/7/72 - 6/1/78	5503
LANDSAT 2	23/1/75 -	3586
LANDSAT 3	5/5/78 -	635
Total	26/7/72 - 1/10/78	9724

A further advantage of remotely sensed environmental data is historical availability. In studies of environmental dynamics, baseline data can be used from air photos taken up to 50 years ago, while total satellite coverage has been available since 1972. Hence, if we allow for the inherent limitations of remote sensing data, we can observe in retrospect many changes in the environment that are due to men and nature.

Resource managers require a wide variety of information on which to base decisions (Hamilton 1978). This information must be detailed and up to date, and must cover large areas. It becomes obvious that computer manipulation of a digital data base is the only economically feasible way of handling massive amounts of data efficiently. An information system would quickly become obsolete unless the data base could be updated at regular intervals. Digital satellite imagery has a significant input to the updating process. It is acquired on a regular basis, is digital in its original format, synoptically covers large areas, and can be obtained very economically. Resource agencies in the Maritimes have already recognized the need for such a system; Cihlar[1] reports on a trend-setting workshop wherein the representatives of various resource interests in the Maritimes initiated the design of a region-wide digital information system for natural resources management. This type of program is not only necessary but inevitable for *all* parts of Canada.

CANADIAN REMOTE SENSING ACTIVITIES

One way to evaluate remote sensing technology is to investigate activities in this field. A comprehensive study of the use of LANDSAT imagery in Canada was conducted in 1977 (Hayes et al. 1977). A representative sample of 100 people were interviewed to determine how they used remote sensing data. A large number of successful applications were reported, many of them in forestry and biophysical mapping. "In view of the number of operational systems reported, it would appear that considerable progress is being made towards moving satellite remote sensing from the confines of research into filling operational requirements. As yet, most of the operational systems...are found in applications involving gross spacial features or change in those features with time such as mapping forest fire burns..." (Hayes et al. 1977).

Another Canadian survey of remote sensing users in the fields of forestry, wildlife and wildlands (Cihlar and Rubec 1979b) showed substantial activity, and of the 359 projects described, 56% were identified as either operational or pilot. The significance of labelling a remote sensing endeavor "operational" is that the principals involved in the work have confidence in the techniques being used and in the quality of the results. In other words, they must believe that their particular use of remote sensing technology is economically justifiable. The 15 categories of objectives for these projects are listed in Table 2.

One subtle indication of the maturation of remote sensing is the use of multiple forms of remotely sensed data in any one environmental monitoring project (Cihlar[2], Cihlar and Rubec 1979b). New forms

---

[1] Cihlar, J. 1979. Renewable resource information systems for the Maritimes. Report of a workshop, Moncton, N.B., 8-12 Jan., 1979. Can. Centre for Remote Sensing, Ottawa, Ont. Intern. Memo.

[2] Cihlar, J. 1979. Can. Centre Remote Sensing, Ottawa, Ont. Intern. Memo.

of data or analysis techniques are rarely used to replace other forms of information completely. Each technique and data type migrates to its most useful and cost-effective role in the scheme of things. Quite often this means that remote sensing is just one of several data forms used in a decision process, and also that several forms of remotely sensed data (color/color infrared films, low level/high level air photos, airphotos/satellite images) can contribute at the same time. The various types of remotely sensed data complement, rather than compete with, one another in their support of more conventional forms of information.

Table 2. Remote sensing applied to forestry, wildlife and wildlands projects: project objectives (Cihlar and Rubec 1979b)

Wildlife habitat mapping (18)[a]
Wildlife habitat monitoring (2)
Fauna census or inventory (10)
Forest types inventory or update (12)
Preparation of forest management plans (6)
General forestry information and information needed for daily work (6)
Forest damage (6)
Forest fire mapping (3)
Land and soils evaluation (8)
Ecological mapping (57)
Geomorphological or geological mapping (15)
Hydrologic or aquatic mapping (3)
Environmental impact assessment (7)
Land use mapping (8)
Mapping to implement land use policies (27)

---

[a] Numbers within parentheses indicate the number of projects reported to have these specific objectives.

The use of LANDSAT imagery for forestry applications in Nova Scotia was evaluated recently by Alföldi and MacAuley[3]. The potential of LANDSAT data is of particular interest to this province for several reasons which can be summarized again by the rule of thumb: Increased altitude for data gathering results in increased economy. LANDSAT-based mapping potential for various forest features was categorized as operational, developmental and research (Table 3). This type of labelling is essential in order to capitalize immediately on those techniques which can be implemented now, and to devise short-term and long-term plans for those requiring additional development or research.

---

[3] Alföldi, T.T. and MacAuley, E. 1979. Forest features mapping from LANDSAT. (unpubl.).

Table 3. Mapping of forest features using LANDSAT imagery[a].

Forest feature	Identified by	Mapping technique		Visual interpretation	Digital analysis	Operational developmental research	Expected accuracy High/Med.	Limitations (clouds, shadows, snow, pixel size)
		Once	Repeatedly					
Clearcutting	shape + color	✓	✓	✓	✓	O	H	partial cuts
Logging roads	shape	✓		✓	X	O	H	narrow roads
Forest fires	shape + color	✓		✓	✓	O	H	small fires
Blowdown	color	✓	✓	✓	✓	D	M	partial damage
Herbicide kill	color	✓	✓	✓	✓	D	H	partial kill
Soft./Mix./Hardwood	color	✓		✓	✓	D	H	broadleaf vegetation
Budworm defoliation	color	✓	✓	✓	✓	R	M	mixed wood
Other diseases	color		✓	✓	✓	R	M	mixed wood
Species identification	color	✓		X	X	R	X	spectral similarities
Regeneration success	color	✓	✓	✓	✓	R	M	broadleaf interference

---

[a] as determined for the province of Nova Scotia (see footnote [3], page 165).

REMOTE SENSING ACTIVITY IN ONTARIO

While there is a fair amount of activity in remote sensing in Ontario, the province both needs and has the potential for substantially more use of this technology.

An environmentally aware public is demanding increased vigilance over our natural resources and more detailed environmental legislation. Because of the increasing popularity and value of timber as an energy source, for the manufacture of paper and for other uses, the geographical limits of merchantable timber are being pushed further and further into Ontario's hinterland. Lack of information about forest conditions in the hinterland makes forest management very difficult. "Uncontrolled clear-cutting in northern Ontario, where the general practice has been to remove all merchantable timber as it is made accessible by a developing road system, has resulted in widespread areas of denudation." (Reed and Associates Ltd. 1978 p.44). There is also a need for more information about northern Ontario wetlands. Whereas previously there was little interest in mapping these extensive and remote "wastelands", now such mapping *is* desirable because of the energy potential of the peat that has been found there in large quantities[4].

It is becoming evident that Ontario needs an environmental monitoring scheme in which the entire province can be observed repeatedly on a regular basis. Frequent observation of the whole province is economically feasible only by means of remote sensing. A combination of aerial imagery to obtain detail for selected sites, and satellite scenes for complete overviews, provides a balanced and cost-effective mixture of data sources.

Ontario has used remote sensing in the form of large-scale black and white aerial photography to monitor forest resources over the past 30 years. The Forest Resources Inventory (FRI) program is in its fourth 10-year cycle of airphoto coverage for Ontario south of 52° north latitude (Zsilinszky 1964, Anon. 1978). Whereas this procedure was considered advanced and was practical in the middle years of this century, it has been rendered obsolete by the availability of modern remote sensing technology (high altitude aerial photography, color and color infrared films, satellite imagery, etc.).

The basis for applying modern, operational and economical remote sensing methods to environmental information needs already exists in this province. Symposia, conferences and workshops on remote sensing technology are held regularly. A variety of courses on air photo interpretation, remote sensing and photogrammetry are offered at Ontario technical colleges and universities. Ontario also boasts one of the two provincial remote sensing associations in Canada (the other being

---

[4] Zsilinszky, V.G. 1979. Pers. commun.

in Quebec). Both the Canada Centre for Remote Sensing (CCRS) and the Ontario Centre for Remote Sensing (OCRS) are located in the province. OCRS is an agency of the provincial Ministry of Natural Resources and provides remote sensing services on a province-wide basis by employing both aircraft and satellite data and the full spectrum of analysis techniques.

It is evident that there is a need to apply remote sensing techniques to the monitoring of Ontario's environment and that we possess the technical and institutional means to do so. Why, then, are remote sensing techniques not being utilized to their full extent? Several factors enter into the answer to this question. One of the major reasons is the relative newness of the technology. The random application of a new technology in areas where it may or may not be useful is an uncertain and slow process. Definitive and organized technology transfer programs can speed up the process. Such programs are now under way at both the federal and the provincial levels. Another reason for the hesitancy on the part of environmental managers to use remote sensing technology is that they want to be able to examine precedents that are relevant to their own operations to ensure that benefit/cost ratios are favorable. Such precedents are understandably difficult to produce in quantity for a technology which is less than 10 years old. But more and more success stories are being reported, and a few are sufficiently well documented to be impressive even to the skeptic.

COST-EFFECTIVE USE OF REMOTE SENSING

Data gathering by means of remote sensing is so different from more conventional techniques that the calculation of relative benefits is subject to serious error. Comparison between ground and satellite sources of data is especially awkward. While a satellite photo which covers 34 225 km^2 of the earth's surface may be purchased for $16.50, this areal coverage would not be attempted in totality by means of field work. Cost comparisons in this case would be meaningless and fanciful. Other intangibles also interfere in the calculation of economic efficiency or benefit/cost ratios for remote sensing. McQuillan (1975) warns that "...ground surveys yield some types of information not obtainable remotely and, therefore, the two methods are not comparable." Strome (1976) points out that some benefits from the use of remote sensing may be in the form of increased productivity per unit cost rather than in real, identifiable dollar savings. He also suggests that many of the benefits are not readily quantifiable, such as sovereignty, quality of life, and so on.

Despite these difficulties, a few examples of economic benefits derived from the use of remote sensing technology are now available and may be examined in the light of the above qualifications. MacAuley[5] reports on his experiments in using small-scale color infrared photography for forest inventory and spruce budworm defoliation monitoring. His conclusions after comparing panchromatic, color and color infrared photography at various scales are that a) color photography is more useful than panchromatic; b) color infrared is more useful than normal color, especially at small scales; and c) small-scale color infrared imagery provides sufficient detail that it could replace large-scale panchromatic imagery. The implication of these conclusions is that with smaller-scale photography (though using a more expensive film) the total costs of photography and interpretation are reduced. Ryerson[6], who did a benefit/cost study of CCRS airborne projects, concurred with these conclusions, and made the following observations:

1. Even using color imagery *at the same scale* at an increase in cost of 10% over pan imagery, savings of up to 50% in interpretation costs were realized.
2. Color IR (CIR) photos at 1:60 000 contain as much information (or more) about vegetation cover as 1:12 000 to 1:24 000 panchromatic imagery.
3. Area coverage can be obtained more cheaply with 1:60 000 CIR photos than with pan imagery at 1:24 000 and *much* more cheaply than with pan imagery at 1:10 000 or 1:12 000.
4. Interpretation costs always exceed image acquisition costs for large areas.
5. With larger-scaled prints, handling and storing of imagery are more expensive.
6. Less experienced (and hence less costly) interpreters can interpret color imagery.

The use of satellite imagery produces even more spectacular benefits. McQuillan (1975) estimated potential annual benefits in the tens of millions of dollars for LANDSAT applications to resource development in northern Canada. Forestry applications (forest fuel mapping, disease control, inventory for volume estimate and management purposes, clearcut and fire burn mapping) alone show a total of over $7 million in potential benefits. The Hayes report (1977) estimated actual benefits of LANDSAT imagery applications and reported total annual cost savings of at least $8 700 000 in 1976 dollars. The portion designated for land use, wildlife and forestry amounted to approximately

---

[5] MacAuley, F. 1979. Remote sensing usage (sic) and needs at the Nova Scotia Department of Lands and Forests. Seminar lecture at Can. Centre for Remote Sensing, Ottawa, Ont.

[6] Ryerson, R.A. 1979. Benefit/cost analysis of the CCRS airborne program. (in preparation)

one-third of the total benefits! While this is encouraging for workers in these disciplines, it was disappointing to note from the report that the apportionment of these benefits by user category (federal government, provincial governments, industry and educational institutions) left the provincial governments with only 6% of total benefits! Yet the provincial governments have the mandate for the *direct* care of natural resources and the environment.

Individual reports of cost savings, though smaller in absolute value, provide direct insight into the day-to-day economy of using a cost-effective technique. Mapping of the 1974 Dryden fire of approximately 38 000 ha cost over $1200 by conventional methods (aerial sketching), while LANDSAT-based image analysis cost only $114.32 (Anon. 1975). On a more grandiose scale, the mapping of northern Ontario from air photos for biophysical classes and surficial geology features was estimated to cost approximately $5 million[4], an unacceptably high price. Using LANDSAT imagery, however, OCRS is able to do the required mapping for $720 000.

The benefits to be derived from using satellite data in a resource inventory or for a monitoring program are not due simply to the smaller-scale imagery and the consequent lower material cost. Significant savings are due to improved management of field activities. Preliminary analysis of the satellite scenes can provide guidance to field crews as to which areas should be ground checked on the basis of the homogeneity and variance of the spectral characteristics of surface features. It cannot be overemphasized that remotely sensed data are used most economically in concert with other forms of information.

FUTURE CONSIDERATIONS

The Canadian user of remote sensing systems has an automatic technology updating mechanism at his disposal. Improved data from new satellites and aircraft sensors are readily available to the user, with almost no initiative required on his part. It is clearly in the interest of remote sensing technologists to provide the best available data to potential users and to develop and test the tools and techniques which provide the most accurate and economical analyses of environmental concerns. All of these technical advances are brought to the attention of users as they become available. This means that the only responsibility left to the user is to choose, evaluate and apply the most beneficial data types and analysis tools for his own purposes.

The most significant advance in remote sensing technology is LANDSAT-D data, which will be available in 1981. The improved spatial, spectral and radiometric qualities of the Thematic Mapper instrument which will be on board the satellite have significant potential for

---

[4] See p. 167.

improving the mapping accuracy of fire burns and clearcuts, better defining narrow logging roads, improving the separation of softwood/mixedwood/hardwood stands, identifying budworm defoliation and other forest diseases, more finely separating land use classes, etc. Potential users need not dread the considerable administrative and technical work that must precede the practical implementation of these improvements. The numerous Canadian businesses, institutions and agencies dealing with the myriad details involved in this new satellite will ensure that the user is presented with a workable tool for his discipline, not just prospects for long-term research.

CONCLUSIONS

Remote sensing technology has matured sufficiently that certain applications may now be considered operational. Potential users in forestry, for example, can rely on small-scale, false color infrared aerial photography for use in forest inventory and mapping of the impact of various natural disasters. LANDSAT satellite imagery may be used confidently to monitor logging activities and burned areas, and other practical applications are imminent. This new tool becomes more cost-effective each year. Today, the resource manager cannot afford to ignore the economy and flexibility of remote sensing technology.

LITERATURE CITED

Anon. 1975. The use of ERTS imagery to delineate boundaries of recent burns and to estimate timber damage. Ont. Min. Nat. Resour., Ont. Centre for Remote Sensing, Toronto, Ont.

Anon. 1978. Forest inventory procedure for Ontario. Ont. Min. Nat. Resour., Toronto, Ont.

Cihlar, J. and Rubec, C. 1979a. User survey of applications of remote sensing in Canada for wildlife, forestry and wildlands and biophysical inventory. Working Group on Forestry, Wildlife and Wildlands, Can. Advis. Comm. on Remote Sensing, Can. Centre for Remote Sensing, Ottawa, Ont.

Cihlar, J. and Rubec, C. 1979b. The 1978 status of operational uses of remote sensing data in forestry, wildlife and wildlands projects in Canada. Can. Centre for Remote Sensing, Ottawa, Ont. Res. Rep. (in press).

Hamilton, A.C. 1978. Remote sensing for renewable resource monitoring in the Maritime provinces. Prep. for Land Registr. Inf. Serv.

Hayes, F.B., Waters, R. and McIntyre, A. 1977. Canada Centre for Remote Sensing LANDSAT data user survey. Dep. Energy, Mines, Resour., Ottawa, Ont. Surv. Rep.

McQuillan, A.K. 1975. Benefits of remote sensing in Canadian northern resources development. Can. Centre for Remote Sensing, Ottawa, Ont. Res. Rep. 75-6AX.

Reed (F.L.C.) and Associates Ltd. 1978. Forest management in Canada. Dep. Environ., Can. For. Serv., Ottawa, Ont. Inf. Rep. FMR-X-102.

Strome, W.M. 1976. Use of remote sensing for land applications. Can. Centre for Remote Sensing, Ottawa, Ont.

Zsilinszky, V.G. 1964. The practice of photo interpretation for a forest inventory. Photogrammetria XIX, 1962-1964, No. 5.

AN INTEGRATED RESOURCE INFORMATION SYSTEM

W.M. Strome
Chief, Applications Division

L.W. Morley
Director-General

D.G. Goodenough
Head, Methodology Section

J. Cihlar
Head, Applications Development Section

and

A.K. McQuillan
Research Scientist, Sursat Project Office

Canada Centre for Remote Sensing
Ottawa, Ontario

For efficient resource management, both extensive background data and up-to-date monitoring information are required from a variety of sources. An integrated resource management system can be a useful and cost-effective tool for those establishing policy and making management decisions.

Pour une gestion efficace des ressources, il faut à la fois beaucoup de données sur les antécédents et une information de la surveillance à jour, provenant de sources variées. Un système intégré de gestion des ressources peut être un outil pratique, efficace et peu coûteux aux responsables qui établissent les politiques et qui prennent les décisions de gestion.

INTRODUCTION

In the past, we Canadians have looked upon our natural resources as vast and limitless, and have seen little need for planning or management. Environmental concerns raised in the late 1960s and early 1970s, followed by energy crises in recent years, have served to increase public awareness of the finite nature of our resources. We are finally beginning to realize that, from now on, we will have to manage these resources much more carefully than we have in the past.

To manage resources effectively, it is necessary to have accurate information on their current status and the factors affecting their use. Such information may be obtained from various sources, but if it is to be readily available in a utilizable form it should be combined in an integrated fashion (Morley 1978, Hamilton 1979). Moreover, many information requirements are common to a number of resource management activities. It may be beneficial, therefore, to develop an integrated resource management information system that will provide all available data pertinent to each resource management problem in a consistent, cost-effective manner. One of the sources of this information that is gaining wide acceptance by resource managers is remote sensing.

In Canada, the major responsibility for operational management of resources (excluding oceans) rests with the provinces. Therefore, the resource management information system proposed here must be designed to meet future operational needs of provincial governments. These needs can be considered in two overlapping categories: (a) cases in which historical data are needed to increase background knowledge about a region; and (b) cases in which up-to-date information is required so that timely resource management decisions can be made. The same data might be used in both cases.

Monitoring may require frequently repeated, full mapping of a region, or only selective updating of background information. Information obtained through mapping is often used in making long-range policy decisions (e.g., in land use planning). In mineral exploration, mapping information is used in identifying possible sites of mineral or oil reserves. Decisions reached in this manner require careful analysis of the available data.

Cases in which decisions must be made quickly, such as when to open the flood gates on a dam, require up-to-date monitoring information from a variety of data sources, in addition to the background information required for policy decisions. In the example just given, background information is essential for developing a model for a watershed area. Timely meteorological observations (on precipitation, temperature, etc.), *in situ* point measurements (of stream flows, snow depth, etc.), and remotely sensed spatial observations (of snow cover area, for example) can serve as inputs to hydrological models designed to predict runoff. Such information can be used in designing policies and making decisions with respect to reservoir level maintenance that will be economical and yet will entail little risk.

INTEGRATED RESOURCE INFORMATION SYSTEMS

The Canada Centre for Remote Sensing (CCRS) has no direct mandate for earth resource management, nor does its staff have the necessary expertise. In some respects we may be considered outsiders to the problem. We note the fact that remote sensing data have potential for effective application to many resource management problems, and that there are other information sources (such as weather observations and "geographic information" data bases) with similar potential. We also note that most of the benefits achieved to date from the use of remotely sensed data have been derived from category a) applications rather than from category b) applications (Hayes et al. 1977); i.e., analyses of potential benefits have shown that the latter should be of greater value in Canada (Clough 1975, McQuillan and Strome 1979). It would be too expensive for every operational resource management agency to develop its own independent integrated resource information system, but a system designed to meet the needs of many users in a region (e.g., a province) could be very cost-effective, particularly since it would meet both mapping and monitoring information needs.

Before designing an integrated information system one must identify the resource managers, their agencies, their conventional sources of information and current methods of information use, as well as their output in terms of management and long-range policy decisions or recommendations. During this identification process, a major task must be to determine the degree of information overlap. If we assume that there is a significant degree of overlap among various applications, an outline of the system, based on the following premises, can be developed.

1) Each resource manager should have immediate access to all up-to-date information he requires to make the best possible decision.

2) Each resource management agency will perceive a need to have its own "data base", which it alone can modify, although others may access it.

3) Interagency rivalry, both constructive and inhibitory, will always exist.

The technologist would like to forget about the third premise, but it may be the most significant in the system design. Although it might be most cost-effective to build a powerful, centralized data processing facility to manage a massive data base, which agency will be given this responsibility, and effective control over the information of all other agencies? In some cases, there may be a logical choice, in others there may not. Even where a single agency operates the total system for all others, this should not be apparent to the individual user. Each resource manager should perceive the system as his own. He alone should be able to update his data base, yet he should have access to all information in the other data bases and should have assistance in managing his own segment. Thus, the system should appear to be distributed or decentralized, whether or not it is in fact.

TRADITIONAL RESOURCE INFORMATION SYSTEMS

Figure 1 illustrates a traditional resource information system. It is assumed that, for example, a province has a number of different agencies (A,B, etc.), each responsible for the management of some specific resources. It is assumed that long-range policy planning is carried out at agency headquarters in accordance with the general policies of the elected government. However, day-to-day detailed resource management decisions may be made either at headquarters or, in many cases, at the regional offices of each agency (e.g., Aa, Ab,..., etc.). In some cases, a regional office might serve more than a single agency, as is illustrated by Ac, Ba in Figure 1.

Each agency maintains its own data base. Each data base utilizes information gathered by the agency and its regional offices or field staff, and, in many instances, information from sources outside the agency. Some outside sources may be used by only one resource management organization (such as α and ε in Figure 1), while others may be used by various agencies. For example, weather data can be used by many different agencies. Similarly, the same remotely sensed data acquired over a given region can often be used for many different resource management applications. It is important to note at this point that the traditional system does not necessarily use computer technology. While the data bases *may* be resident on computers, they could also be in the form of maps, tables or reports. Entry of new information into the data bases, or access to the information, may be through computer terminals or it may be strictly manual.

There are a number of potential sources of inefficiency in the traditional system. The most obvious is the unnecessary duplication of effort in data gathering. Different agencies may collect similar data over the same area where a single data collection effort could serve all the groups concerned; several organizations may independently develop methods to utilize data from external sources, such as weather information and remote sensing data; a great deal of effort may be expended by several organizations in maintaining similar data bases, each containing considerable common information.

One possible solution to the problem would be to establish an interagency facility charged with maintaining a single large data base for the participating agencies, and with coordinating all data collection and analysis. However, experience in many related fields has shown that this approach is not practical because such a facility could not be uniformly responsive to the needs of its user agencies.

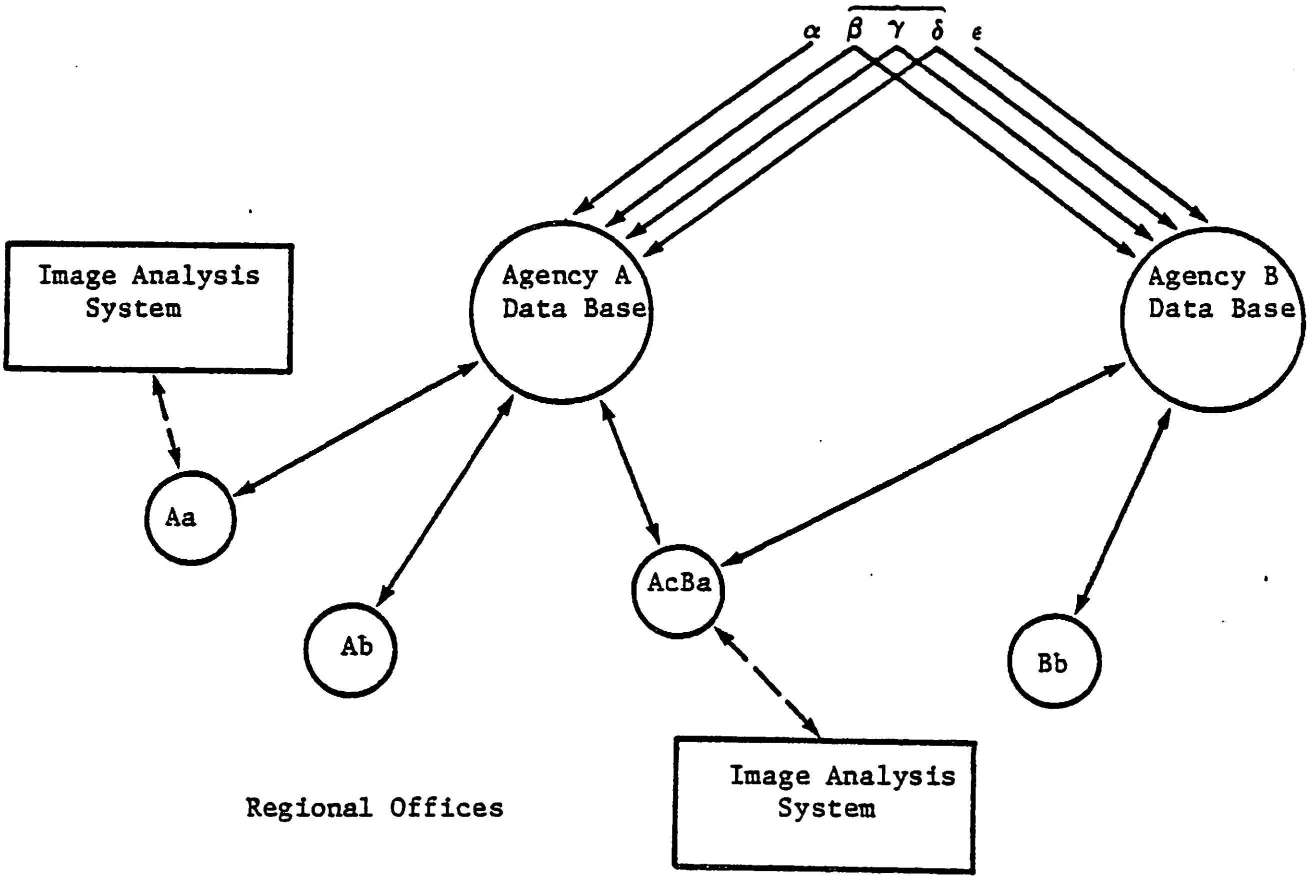


Fig. 1. Typical traditional resource management information system.

PROPOSED RESOURCE INFORMATION SYSTEM

The following system is proposed to meet the information needs of resource managers. The heart of the system is a computerized geographic data base, or a number of such data bases interlinked in some fashion. All information is coded and accessed on the basis of its position, and where relevant, its time of acquisition.

Since positional references may be in the form of various map projections or township reference systems, it should be possible to query the data base positionally in any user-selected manner. Each user has full access to what appears to him as his own agency's private data base. However, this will not only include the information gathered by his organization, but will also appear to be augmented by the data input of other agencies. Any agency may modify its own data, but not those of the others.

Frequently, it is desirable or necessary to use digital image analysis techniques to determine the required information from remotely sensed data. At present, only a few systems capable of performing this type of analysis exist in Canada. Anyone wishing to use these systems must travel to the few places where they are located, but this is a great inconvenience, and consequently resource managers have been unwilling to accept these systems.

The approach to resource information systems suggested here and illustrated in Figure 2 requires at least some degree of computer/communication technology. The various agencies maintain their own data bases, but *these must be compatible with one another.*[1] The key to the system is the element labelled "Switchboard", a computer which knows where each type of information resides. It has its own internal data base, which may include information from outside sources such as remote sensing data. Regional offices and agency headquarters are linked to the data bases and to each other by computer terminals. The computerized data bases need not contain all the information, but they must indicate where one can find it.

The principal advantage of the proposed system is that it avoids duplication of information updating and handling. For example, a single current land-use data base could be accessed by all agencies, or weather data from a single source could be incorporated into several data bases. Another very important advantage of the proposed system is that it gives resource managers access to much more information than their respective agencies could afford to collect on their own--information that may enable them to make more confident, timely and cost-effective management decisions. The biggest savings would be in the collection of up-to-date information, which is the costliest to collect. Heretofore, many agencies simply could not afford to collect such data.

---

[1] In the very few cases in which substantial digital data bases already exist, it may not be feasible to convert them to a new format, but at the very least, a compatible interchange format will have to be developed.

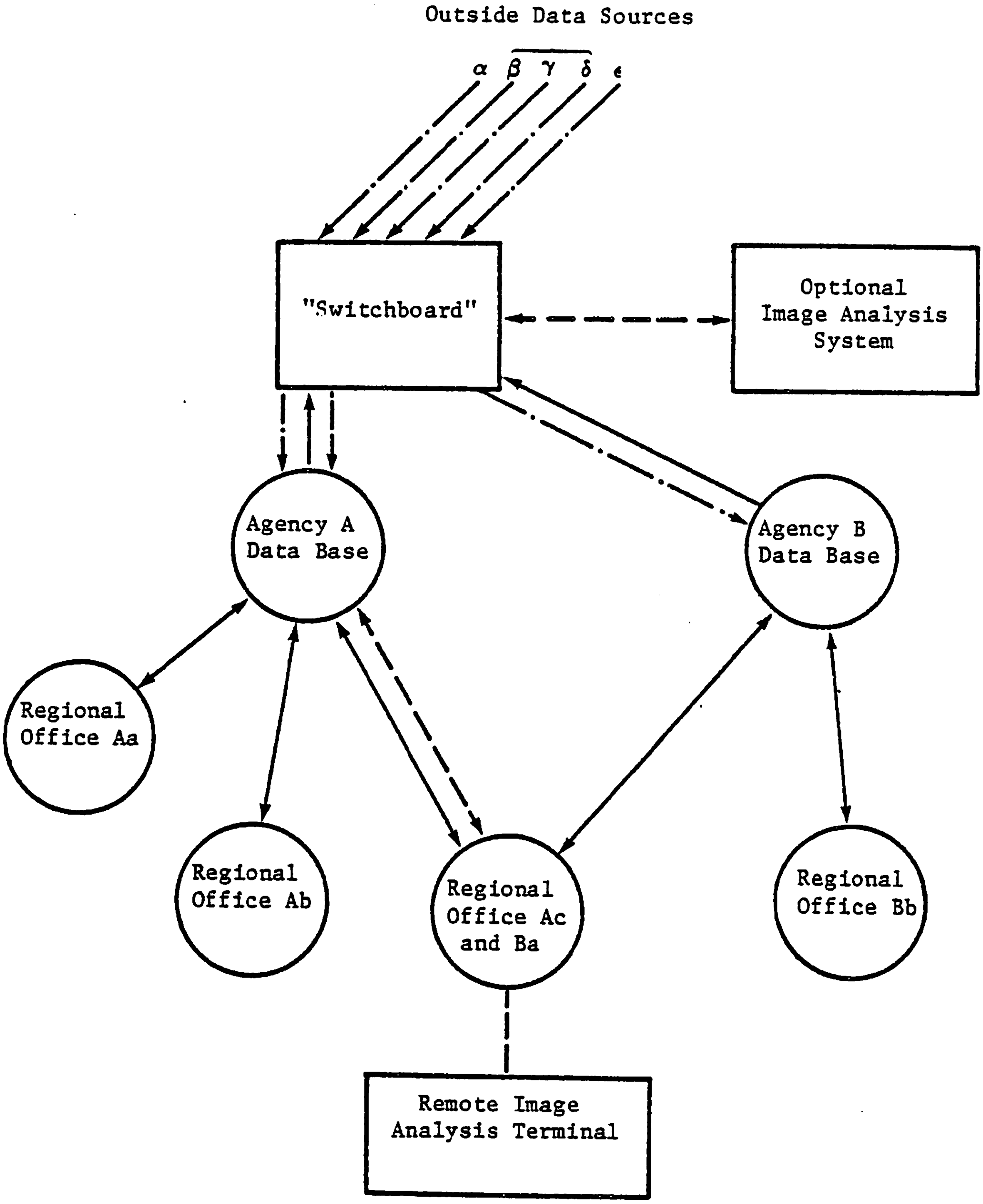


Fig. 2. Proposed resource management information systems.

The system would also be able to handle remote sensing data efficiently. For a given region, the same data might be viewed by many resource managers in an unprocessed form, or the required information might be obtained by using an image analysis system as illustrated in Figure 2. Either unprocessed or analyzed information might be used in the regional offices.

As higher-resolution, better-quality remote sensing data become available in the 1980s, more applications will benefit from the use of image analysis techniques. At present, few if any resource managers have direct access to systems capable of performing this type of analysis. As the cost of these systems is generally quite high, only a few agencies could afford complete systems of their own. On the other hand, if the cost were to be shared among all agencies, a central image analysis system could be incorporated into the network, perhaps as part of the "Switchboard". Some functions of the analysis facility could then be accessible to all terminals and full capability could be realized through special remote image analysis terminals.

SUMMARY

The thesis of this paper is that it should be possible to provide more effective and better-quality resource management through the use of an integrated, but decentralized regional resource information management system. The system described could minimize duplication of effort and provide the maximum amount of relevant information to resource managers at the operational level. The concept described herein needs much more development before it can be implemented; however, the time is ripe for considering such systems. Resource management agencies are beginning to convert their data bases from manual/paper operations to computer systems. It is possible to plan the compatibility and interconnectability of new systems now: indeed, if this is not done now, it may be prohibitively expensive in the future, especially if each agency develops its own independent system. In particular, resource and environmental management could add a new dimension to its function--that of obtaining and acting upon up-to-date information that was previously beyond reach.

ACKNOWLEDGMENTS

The authors would like to thank Jim O'Neill and Bill Bruce of the Canada Centre for Remote Sensing for their careful review of the early drafts of this paper and for their invaluable suggestions and comments.

LITERATURE CITED

Clough, D.J. 1975. Remote sensing and economic value of errors in wheat forecasting. p. 457-488 *in* Proc. Third Can. Symp. on Remote Sensing.

Hamilton, A. 1979. A suggested approach to the development of environmental monitoring centres. Annu. Meet. Can. Adv. Comm. on Remote Sensing.

Hayes, F.E., Waters, B.R. and McIntyre, A. 1977. Canada Centre for Remote Sensing LANDSAT data user survey. Dep. Energy, Mines Resour., Ottawa, Ont. Rep. No. 2-1977.

McQuillan, A.K. and Strome, W.M. 1979. An evaluation of LANDSAT-D for Canadian applications. p. 957-964 *in* Proc. 13th Internatl. Symp. on Remote Sensing of the Environ. Ann Arbor, Mich.

Morley, L.W. 1978. Regional monitoring centres. Can. Centre Remote Sensing Seminar Ser.

PANEL DISCUSSION

Moderator: K.A. Armson
Special Advisor
Forest Regeneration
Ontario Ministry of Natural Resources
Toronto, Ontario

Members: J.H. Cayford
Director
Great Lakes Forest Research Centre
Canadian Forestry Service
Sault Ste. Marie, Ontario

J.H. Flowers
Regional Forester
North Central Region
Ontario Ministry of Natural Resources
Thunder Bay, Ontario

L.W. Morley
Director General
Canada Centre for Remote Sensing
Department of Energy, Mines and Resources
Ottawa, Ontario

V.G. Zsilinszky
Associate Director
Ontario Centre for Remote Sensing
Ontario Ministry of Natural Resources
Toronto, Ontario

J.H. Cayford: I would like to consider the present and future role of the Great Lakes Forest Research Centre in remote sensing. Very few speakers at this symposium are affiliated with our Centre or with the Ontario Forest Research Centre; hence, I must conclude that there is little application of remote sensing technology in the programs of these Centres, and I wonder if this is a desirable state of affairs. Jack Flowers stated that remote sensing is one of the most exciting advances in technology in the past 10 years, yet he has apparently observed little excitement among foresters in Ontario.

The research centres in Ontario are charged with the responsibility of seeking solutions to important forestry problems in the province. Our respective staffs have considerable expertise in various aspects of forestry, but are they sufficiently knowledgeable about remote sensing technology to incorporate it into their proposed solutions to forestry problems? I think their difficulties are compounded by the relatively low priority given to forest research in recent years. Recruitment has been minimal, and consequently our present staff have had little formal training in modern remote sensing technology. It is clear from this symposium that remote sensing can contribute a great deal to the solution of forest management problems and that most subjects discussed here are being addressed by workers at our forest research centres.

Where do we go from here? First of all, we must ensure that our staff become more familiar with remote sensing technology. Therefore, over the short term, training is our first need. Because we must consider ourselves users of remote sensing technology rather than researchers in this field, we need to establish regular communication with remote sensing specialists. The current communication gap has been noted several times in the course of this symposium. We also need more cooperative projects of the type discussed by Brian Stocks in which researchers, remote sensing specialists and forest managers are involved.

J. Flowers: I believe that we should be aiming for rapid and effective implementation of remote sensing techniques that have been available to us for some time. This will require much study and effort by all of us. The question is often asked: "How do we transfer this technology from the experts to the users?" In my opinion, a four-phase effort is required.

First, remote sensing specialists will have to sell their technology to senior professionals in the various jurisdictions. They must convince them that they are offering something which can be used somewhere in their organization, whether it be in the public or in the private sector. As I stated in my paper earlier in this symposium, if senior professionals had picked up some of these techniques at the outset, they would have an efficient system in place by now.

Second, senior professionals must decide that they want this technology and that they are going to use it. Then they must ensure that staff at all levels in their organization learn the technology. Training must be mandatory: an ordered transfer of remote sensing technology requires the active participation of staff throughout the organization.

Third, financial and moral support are essential. We have had many indications, in the course of this symposium, of just what the remote sensing community can do for us, but a great deal of effort will be required to implement remote sensing programs.

Fourth, after the technology has been successfully applied in pilot projects, cost-effective programs must be set up for uniform application throughout the province. Variations may be permitted, but the major features of the program should be the same throughout the province.

P. Kourtz: Remote sensing provides the resource manager with a wide variety of tools, many of which are ready to be used now. The real question is: "What can be done to integrate these systems into our day-to-day management procedures? I believe that the time for field demonstration projects has passed, since we know the capabilities and values of the methods in question, such as the method of integrating large-scale photography into forest inventory.

The usefulness of training at the intermediate level of management is limited, in my opinion, because there is little incentive for these managers to develop new technologies. They generally lack time, money and interest. If remote sensing technology is to be used, it must be supported at the highest levels of government.

The British Columbia Inventory Project provides an excellent example of this approach to technological application. First, the government passed some imaginative legislation which set goals requiring the use of new technology. Second, substantial funds were committed to the acquisition of the technology. Third, a major reorganization was undertaken within the Forest Service so that the new technology could be utilized.

The most persuasive arguments for establishing a new technology are not necessarily the most rational. As Larry Morley pointed out earlier this morning, one of the main reasons for federal government financing of advanced research in remote sensing technology was the conviction that, without such research, we would be in the unenviable position of knowing less than other countries about our own resources. Perhaps the most convincing argument that can be presented to Ontario legislators is that the technology we are using now is outdated and that other provinces are much more advanced than Ontario in their use of remote sensing technology to improve forest management.

L. Morley: The concept of technology transfer as a process that begins at the top and filters down to the lower levels of an organization has been in operation at the Canada Centre for Remote Sensing for the past six or seven years. However, if we look at the history of the development of innovative technology, we will find few similar examples: implementation is usually from the working level upward, with a hard sell coming from the working level. At this point the policy makers and politicians will approve the program and provide the funds. I was brought up to believe that the rewards go to the worker in the field who can see a bit beyond his nose and hence is able to develop new technologies and techniques. In remote sensing, these people are called the "change agents", and they are not hard to identify. They are usually workers at the operational level who see the importance of a new technology and explore the ways in which it can be used.

In foreign aid work, countries lacking a resource management infrastructure will very often, with outside funding and assistance, move into remote sensing and combine it with their management programs right from the start. Consequently, if you want to see the application of some of the most innovative techniques in remote sensing, go to the developing countries. For example, many tropical countries have satellite imagery to prove that they have 30 to 40% less forest cover than their best estimates had indicated.

Integration of resource management systems for oceanography is easier to achieve than integration of terrestrial resource management systems because only federal agencies are involved in the former. However, because microwave sensors have given us so much information, defense specialists in the United States and Canada are becoming alarmed at the prospect of seeing so much information in the public domain and consequently they will be putting the brakes on this work. It would appear that terrestrial resource management systems will be integrated before systems dealing with our ocean resources, in spite of the organizational problems inherent in the former. Some agencies may be jealously protecting their mandates within their own disciplines but the broader aspect of federal-provincial integration does not appear to present problems.

Among the forthcoming developments in satellite technology is LANDSAT 'D', which is designed to eliminate the common complaint, voiced most frequently by workers in agricultural research, of limitations imposed on the resolution element of the imagery. LANDSAT 'D' will also provide better spectral resolution and thereby permit better analyses of LANDSAT data. A French satellite to be launched in 1983 will provide

10 m resolution for some of its data output. This satellite will also have facilities for programming side-looking sensors to give overlap coverage of the vertical sensor and provide stereo viewing of the terrain with a 10 m vertical resolution capability.

With respect to microwave satellites, we have already had SEASAT, which provided 20 m resolution of black and white radar that could penetrate cloud cover. SEASAT has applications to forestry which will be made available shortly. The HCMM satellite has been launched, but we in Canada have not had the funds to study the output of this satellite. It provides day and night temperature of the areas surveyed so that their thermal inertia can be calculated. These data will be available from satellites to be launched in future.

When remote sensing technologies were being developed, the universities were in dire financial straits. Professors who had explored remote sensing technology saw its potential but could not convince their administrations of the need to establish new courses and chairs in remote sensing. There have been so many competing alternatives that remote sensing has not done as well in the universities as we had hoped. Consequently, we are going to fall behind American and European universities in remote sensing. Professor Howarth of McMaster University has completed a report on the status of remote sensing in education, and I am hoping this report will persuade universities and governments to fund university research and courses on remote sensing.

V. Zsilinszky: With respect to the comment that the development of remote sensing requires a push from the top and the counter argument that it needs a push from the bottom, it is my opinion that the push must come from both directions. Once those at the working level have provided the documentation and information needed to sell the program, managers should have a platform from which to launch it successfully. I believe that we have begun to reach the bottom levels from which the response is expected to come and, as Jack Flowers has indicated, field officers are beginning to exert pressure on top-level managers to make policy decisions.

Why is remote sensing required for resource management? The question has been answered at this symposium by the resource managers themselves, so I need not repeat their response here. The message has also come through that there are gaps in our information and communication difficulties between user groups and the remote sensing community; hence my answers to the question "Where do we go from here?" are based on a consideration of the stated needs for remote sensing in management and of the existing communication gaps. They may be summarized as follows:

1. The full range of techniques and benefits of remote sensing is available to the resource manager. LANDSAT, radar, thermal sensing, and all scales of aerial photography are of potential use to him.

2. Users must understand that remote sensing technology is a dynamic field which is continuing to develop in three areas: 1) research and development, 2) applications development, 3) transferable or operational capabilities.

3. The remote sensing community should attempt to resolve communication problems, but the user community must be prepared to receive the communication.

4. There are two aspects to communication: information and training. As far as OCRS is concerned, the information program includes seminars, lectures and workshops. An annual report on OCRS activities is in press, and various publications have been produced A proposal for the transfer of technology from OCRS to the private sector is in the final draft stage.

5. Special courses are offered by OCRS, and training aids are being devised. We will have to ensure that our training programs complement the programs of existing educational institutions.

Discussion

Dr. D. Burger, Head of the Ontario Forest Research Centre (OFRC), noted that research responsibilities in remote sensing had been given to OCRS, while OFRC had been concentrated on researching problems relating to the growth of the next forest crop. However, he expressed interest in exploring how recent developments in remote sensing technology such as "the use of thermal sensing for locating frost pockets, and the use of near-infrared imagery for evaluating regeneration success" could facilitate research in the fields of ecology, physiology and genetics.

Considerable discussion ensued about how to improve technology transfer and education to ensure that up-to-date technology was being used in Ontario. The point was raised that considerable research has been undertaken in the last six or seven years and between 10,000 and 20,000 papers have been produced. This represents a great deal of information which can be transferred to the operational level of forest management only through a good staff training program.

Several educators lauded the recent emphasis on the need for improved technology transfer and education, pointing out the need for both short- and long-term approaches and their difficulty in keeping up to date with progress in this dynamic field of study. The need to improve communication between educators and staff of provincial agencies concerning training and education was emphasized, and recommendations were made to form a committee to study the problems and to develop an educational program.

The advisability of "technology push" from upper echelons of management was also questioned. It was felt that there is a definite need for some sort of stimulus so as to avoid delays in the transfer of technology but that this should come from the operating level and should take effect through a process of "osmosis". However, discussion throughout the symposium revealed this to be a point of contention.

More aggressive action was urged to improve satellite image analysis, to explore potential applications of satellite imagery, and to integrate satellite imagery with conventional aerial photography. It was claimed that management constraints and not technological constraints were limiting faster progress in these areas.

SUMMARY

SUMMARY

In his concluding remarks, W.K. Fullerton, Director of OMNR's Forest Resources Branch, commented on the departure of the Remote Sensing Symposium from the general objective of COJFRC symposia, namely the transfer of technology. In this instance, the program strategy was to provide Canada's leading researchers in the field of remote sensing with a forum in which to describe the current state of knowledge. The next step, according to Fullerton, is for forest managers to re-examine their views on how this technology can be used in forest management. The needs they express will form the basis of an effective program of technology transfer.

The need for a comprehensive training program was acknowledged repeatedly by forest managers. It was pointed out that OCRS, in recognition of this need, has already initiated a series of training sessions with field staff.

Mr. Fullerton noted a number of the more exciting technological advances such as the digitization and enhancement of data and thermal sensing, and urged forest managers to incorporate them in the forest management process. He warned against letting the "institutional inertia" of OMNR's present organizational infrastructure retard or even prevent the implementation of new technological processes. Every forest manager must become a "change agent", doing his or her part to initiate, develop and utilize the most modern methods available to gather accurate information about Ontario's forest resources.