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Remote Sensing Technology Transfer to Operational Use in Canadian Forestry

J. Cihlar, L.C. Goodfellow, and T.T. Alfoldi
Canada Centre for Remote Sensing, Ottawa

ABSTRACT

The process of technology transfer from the developers to the adopters has been effected in Canada primarily through two mechanisms: user liaison and joint projects. The effectiveness of these mechanisms can be illustrated through a review of several examples in forestry which is a key industry in the Canadian economy.

REMOTE SENSING TECHNOLOGY TRANSFER TO
OPERATIONAL USE IN CANADIAN FORESTRY

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1. INTRODUCTION

As a natural renewable resource, the forests play a key role in the Canadian economy. To illustrate, wood production and paper manufacturing account for 14.5% of Value Added* for all of Canada, while in British Columbia, this proportion rises to 52.1% (Statistics Canada, 1977). Perhaps equally important is the fact that the forest industry provides job opportunities and an income source in regions where few other economic activities are possible. Given its role in the regional and national economies, it is important that the forests be capable of providing sustained or expanded yield.

A previous study of the forest resource in Canada (Reed & Associates, 1978) has shown that although the average harvest does not exceed the annual allowable cut in most provinces, significant timber supply problems currently or potentially exist in some forest zones of five provinces. Problems related to access, matching species and log specifications with existing processing plants, and to the balancing of local supplies and processing capacities further compound the current forest management difficulties.

A prime requirement for proper forest management is the availability of appropriate, accurate and timely information about the forest resource. Because large areas must be surveyed and are frequently difficult to access, remote sensing can play a major role in providing such information.

Interpretation of forest stand types is routinely performed using black-and-white aerial photographs. Colour aerial photographs are being used increasingly as a standard inventory tool. In recent years, significant progress has been made in developing other remote sensing tools which may be used to advantage in acquiring information for forest inventory and management purposes.

2. DEVELOPMENT OF FORESTRY REMOTE SENSING APPLICATIONS

In Canada, most of the general research and development in remote sensing applications to forestry has been undertaken by various institutions of the Canadian Forestry Service in the federal Department of Environment. In addition several provincial groups have been active in identifying techniques relevant to their special problems. Significant progress has been made in developing suitable methodologies to use Landsat data, small and medium scale colour aerial photographs, large scale photography, and supplemental (35 or 70 mm) aerial photography.

2.1 SATELLITE DATA APPLICATIONS

In a study conducted prior to the launch of ERTS-1 later renamed Landsat-1 (Working Group on Forestry and Wildlands, 1971), major potential applications of the satellite data were considered to be broad ecological mapping of the northern territories; recognition and classification of major landforms; and the location of large fires in the northern tundra and forest. At that time the resolution of the multispectral scanner was considered too low to give much new information of practical value in forest management.

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*Value Added for an industry is the residual derived by deducting the value of goods and services purchased and used in the production process from the value of goods and services produced by the industry.

FOREST FEATURES MAPPING FROM LANDSAT - CURRENT STATUS*

FOREST FEATURE	IDENTIFIED BY	MAPPING TECHNIQUE: ONE TIME	MAPPING TECHNIQUE: MULTI-TEMPORAL	VISUAL INTERPRETATION	DIGITAL ANALYSIS	OPERATIONAL DEVELOPMENTAL RESEARCH	EXPECTED ACCURACY HIGH/MED.	LIMITATIONS (CLOUDS, SHADOWS, SNOW, PIXEL SIZE)
Clear Cutting	shape+colour	Y	Y	Y	Y	O	H	partial cuts
Logging Roads	shape	Y	P	Y	X	O	H	narrow roads
Forest Fires	shape+colour	Y	P	Y	Y	O	H	small fires
Blowdown	colour	Y	Y	Y	Y	D	M	partial damage
Herbicide Kill	colour	Y	Y	Y	Y	D	H	partial kill
Soft./mix./Hardwood	colour	Y	P	Y	Y	D	H	broadleaf vegetation
Budworm Defoliation	colour	Y	Y	Y	Y	R	M	mixed wood
Other Diseases	colour	P	Y	Y	Y	R	M	mixed wood
Species I.D.	colour	Y	P	X	X	R	X	spectral similarities
Regeneration Success	colour	Y	Y	Y	Y	R	M	broadleaf interference

* Prepared in a joint project between CCRS and the Nova Scotia Department of Lands and Forests

Legend: Y = Yes (preferrable operatioally); P = Possible; X = Not technically feasible; O = Operational; D = Developmental; R = Research; H = High; M = Medium.

First results of ERTS image analysis indicated that vegetation, roads, railroads, powerlines, logged areas, lakes and dams could be monitored to provide the forest manager with an overview of the management unit and its surroundings (Lee, 1974). General vegetation categories (non-forested classes including cut-overs, meadows, grassland, urban land, and forest stand differentiation based on fire or regeneration history) could be distinguished (Oswald, 1974). Major forest damage caused by sulphur dioxide fumes (Murtha, 1974), by tornadoes (Moore, 1974) and, in some cases, by insects (Beaubien and Jobin, 1974) could be located. Sayn-Wittgenstein and Wightman (1975) and Sayn-Wittgenstein (1977) summarized these earlier remote sensing applications to forestry and assessed the potential of Landsat data in dealing with current forestry issues.

In recent years, numerous forestry projects have employed Landsat MSS data. Forest fire burns have been successfully mapped in operational programs in Ontario (Boissoneau, 1975), Quebec (Laframboise, 1975; Letarte, 1978), Manitoba, Northwest Territories and elsewhere. Forest roads have been mapped using visual interpretation of standard (Jobin and Beaubien, 1974) or digitally enhanced (Kourtz and Scott, 1978) Landsat images. Numerous studies aimed at mapping clearcut areas through visual interpretation of Landsat data were carried out (Murtha and Watson, 1975; Lee, 1975; Kourtz and Scott, 1978; Jobin and Beaubien, 1974). Consistently good accuracies were obtained from visual interpretation of raw or digitally enhanced Landsat products, while results of digital analysis varied somewhat depending on the study area and the analysis technique used. Sensitivity of Landsat MSS data to insect damage has been demonstrated by Murtha and Harris (1978). The current state-of-the-art in Landsat applications to forestry has been summarized in a joint project between CCRS and Nova Scotia Department of Lands and Forests (Table 1).

The status of operational Landsat imagery applications in Canada was documented in the 1978 survey conducted by the Forestry, Wildlife, and Wildlands Working Group of the Canadian Advisory Committee on Remote Sensing (Cihlar and Rubec, 1980). Of the 83 forestry reports returned, 33 and 55 were categorized as operational and research projects respectively. Some of the applications categories were forest inventory, damage, fire burns mapping, and change monitoring. Landsat data were used in almost a third of the reported projects. Most of the operational projects employed visual interpretation, while the tendency was toward machine-assisted analysis in R&D projects. Considering all operational projects (wildlife habitat, forestry, ecological), Landsat data were used as a primary or secondary remote sensing data source more often than all other remote sensing data except black-and-white aerial photography. This has been attributed to Landsat data availability, regional overview and frequent temporal coverage (Cihlar and Rubec, 1980).

2.2 SMALL AND MEDIUM SCALE COLOUR AERIAL PHOTOGRAPHY.

Whereas the use of black-and-white aerial photography for forest inventory has been well established for many years, the value of colour photography was explored in numerous Canadian studies during the 1970's (Cihlar et al., 1980). Normal colour and colour infrared (CIR) imagery has been acquired by the Canada Centre for Remote Sensing for various forestry projects (Cihlar, 1978). Normal colour photography at a scale of 1:10,000 is now routinely used in the Nova Scotia forest inventory program (McAuley, 1979). The feasibility and effectiveness of conducting an operational inventory for a forest management area from 1:50,000 CIR photographs was demonstrated by Dempster (1977). Colour infrared photography at 1:50,000 has also been successfully used to map 6 species types, 5 crown closure classes, 5 height classed, 5 land capability classes, 2 topographic operability classes, and 4 defoliation classes for an area in Nova Scotia (MacAuley, 1978). Major forest species associations were successfully mapped from CIR photos at 1:160,000 by Nielson and Wightman. (1971). To map partial and total forest fire burns, Gignac (1979) developed methodology which permits updating 1:20,000 maps by using 1:120,000 CIR photographs and a stereo transferscope. The feasibility of detecting and mapping certain types of forest damage has also been demonstrated. For example, Murtha (1972) mapped SO_2 damage from a 1:160,000 CIR imagery. Beaubien and Simard (1979) were able to accurately delineate several spruce budworm mortality classes on spring CIR photos (5 classes at 1:160,000, 3 classes at 1:110,000), each class containing a percentage range of dead trees.

The cost of colour films and past inconsistency of colour reproduction for CIR film products have inhibited a more widespread use of these materials in forestry programs. Recently, Cihlar et al (1980) showed that the cost differential between black-and-white (B&W), normal colour, and CIR photographs is not large at the current prices charged by Canada's National Air Photo Library. These authors derived a relationship between the scale factors and the costs per frame which are required to cover a unit area with different film types. Considering only the cost of film purchase, processing and contact duplicating, they concluded that the cost of B&W prints (Kodak film 2405) at 1:10,000 for a given area would be the same as if the area were flown with CIR film (Kodak 2443) at a scale of 1:16,000. Given the much higher information content of CIR photos, this tradeoff is rather appealing. The colour balance consistency has markedly improved in recent years as a result of methodological developments reported by Fleming (1978) and others.

2.3 LARGE SCALE AERIAL PHOTOGRAPHY

In the 1960's and 1970's, several large scale photo (LSP) sampling systems were developed and tested in Canada. These can be used to acquire forest tree and stand measurements without extensive fieldwork. Since the acquisition of forest measurements from photographs is faster and cheaper, albeit less precise than that from ground surveys, photo sampling and ground sampling can be combined in the most cost-effective manner.

Each LSP system has been designed on the basis of technical and economic considerations. The system developed by the Forest Management Institute (FMI) consists of a camera mount, a 70 mm camera, a camera control unit, a tilt indicator and a radar altimeter (Aldred, 1975). Integrated Resources Photography Ltd. have developed a system containing two simultaneously firing wingtip cameras (Williams, 1980). The Northern Forest Research Centre design has two 70 mm cameras with different focal length lenses and a radar altimeter (Kirby and Hall, 1980). A single 70 mm camera without the altimeter has been tested at the Ontario Centre for Remote Sensing (Jano, 1980). The British Columbia Forest Service has attached a boom with two 70 mm cameras to the jack points of a helicopter fuselage parallel to the flight direction (Bradatsch, 1980).

Several of the above systems have been demonstrated successfully in resource surveys. The FMI system is used in provincial forestry inventory in Alberta (Aldred and Lowe, 1978). The B.C. Forest Service system is routinely used for forest inventory and update (Hegyi, 1980). A large-scale forest inventory project is currently underway in the Yukon (Kirby, 1980) using the Northern Forest Research Centre design.

Numerous interpretive applications have been developed using a variety of configurations of 70 mm and 35 mm cameras (Harris and Dawson, 1979; Zsilinszky et al., 1979). These smaller format cameras can be mounted outside the airplane's fuselage or outside a helicopter cabin, resulting in minimal or no structural alterations to the aircraft. Such systems are inexpensive, flexible, and simple to operate.

3. TECHNOLOGY TRANSFER MECHANISMS

Technology transfer can be defined as the process whereby new techniques and equipment are tested, and knowledge and expertise in these are gained by a user agency to better fulfill its resource management responsibilities. The goal of the transfer is to enable the recipient agency to use the new technology through its integration into on-going programs of the agency. Technology transfer follows the path of innovation diffusion through five phases (Rogers, 1962): creation of awareness, generation of interest, evaluation of the technologies, trials of the methods, and adoption of technologies relevant to information needs of the recipient.

Technology transfer implies an interaction between the developer and the adopter. However, the degree of participation by each group may vary depending on factors such as the current level of competence, commitment and interest of the adopter in the technology; the degree of commitment to transfer by the developer; stage of the technology transfer process; administrative framework; and resources available to both parties. The two transfer mechanisms used most extensively in Canada are user liaison and joint projects.

3.1 USER LIAISON

User liaison consists of the provision of remote sensing consultation, training, and technical support to agencies who wish to adapt developed technology to their operations or to assess the feasibility of such adaptation. The Canada Centre for Remote Sensing has been engaged in user liaison since its establishment in 1972. Ongoing liaison activities include answering technical questions about capabilities and limitations of various methods, presentations and workshops on specific aspects of remote sensing, recommending optimum approaches to solving specific resource inventory or monitoring problems, providing liaison with discipline-oriented groups and provincial organizations, and assisting in the evaluation/transfer of remote sensing-based methods to user agencies. Three specific examples are described below.

Scientific liaison for digital image analysis. The CCRS Image Analysis System (CIAS) is available to staff of other agencies for conducting projects aimed at evaluating the applicability of satellite and other digital data as a resource monitoring tool. Since investigators from such agencies frequently have inadequate experience with digital image analysis, CCRS assigns a liaison scientist to each project. The liaison scientist and the investigator analyse the problem to be addressed, and jointly design a procedure which is most likely to provide the required answers. The liaison scientist assists in conducting the analysis to ensure that the procedures and the significance of the results are understood. Results of these projects are typically described in technical documents. A summary of such documents has been prepared by Dixon and Cihlar, (1980).

Principal investigator support. In the development of new applications of remotely sensed data, advanced sensor and data processing technology are often required but not generally available. The "technology" agencies can effectively assist in the developmental process by making their facilities available to external researchers. As an example, principal component enhancement software was developed on CCRS image analysis equipment by Dr. M. Taylor from the Defense and Civil Institute of Environmental Medicine (Taylor, 1974). Subsequently, a methodology for using it for forest fuel types mapping was successfully developed by Dr. P. Kourtz from the Forest Fire Research Institute (Kourtz and Todd, 1975).

3.2 JOINT PROJECTS

Cooperative projects between the developers and adopters are the most effective technology transfer mechanism because the performance of the new technology can be assessed in the environment where it would eventually be used. They also serve as an educational tool for both groups: the developers learn to understand and appreciate "real world" problems of the user agency, while the adopters gain knowledge and experience concerning the new technology.

Cooperative projects in remote sensing are undertaken at various stages of the applications development process. At the developmental stage, user agencies assist in identifying problems to be addressed, in the provision of essential supporting non-remotely sensed data and to various degrees in data analysis. The R&D requirements take precedence in project design and the technology development agency provides the project leadership. During the demonstration phase, assessment of the methodology in an operational environment is of principal interest. The quality, timeliness and cost of information provided through the new technique are evaluated. User requirements and performance criteria take precedence at this stage, while the technology developer ensures that the new procedures are applied properly. It should be noted that the boundary between the two phases is seldom distinct and a single project may exhibit features of both. Several examples of cooperative projects are described below to illustrate the various joint project configurations encountered in Canadian forestry.

Cooperative forestry project in Quebec. The project "Télédétection-foresterie", due to be completed in late 1980, has been designed to demonstrate the capabilities and limitations of Landsat MSS and RBV data and of high altitude CIR photography for the provision of the following information in an operational environment (Audet, 1979): forest inventory maps at 1:125,000; forest road maps (location and class); at 1:250,000 updates of forestry maps at 120,000 showing major forest changes such as fires, cutovers, epidemics, blowdowns, new forest roads; spruce budworm mortality maps at 1:20,000, and the progress of regeneration at the scale of 1:20,000. Coordination of activities for this project is the responsibility of a committee composed of representatives of the cooperating agencies; le Ministère de l'Energie et des Ressources du Québec, the Canadian Forestry Service, l'Université Laval and the Canada Centre for Remote Sensing. Each agency provides expertise in specific areas and supports the project with manpower and funding. Le Ministère de l'Energie et des Ressources, as the adopter, has defined the 5 sub-projects based on its existing needs and problems.

Application of large scale photos to forest inventory in Alberta. Aldred and Lowe (1978) reported the results of a successful experiment aimed at transferring large scale photography techniques to a provincial agency. Following successful development of a large scale photo methodology for use in forest inventory by the Forest Management Institute, the Alberta Forestry Service (AFS) requested that a full-scale trial be conducted on one of their forest management units. The trial was to demonstrate the use of large scale photos as a primary source for tree data in a large, volumetric forest inventory and to provide a comparison of the accuracy and cost of photo plot data with those from conventional field plots (Aldred and Lowe, 1978). Performance requirements for the new method were specified by the AFS. A scientist from FMI worked with the AFS personnel for the duration of the project. His tasks included adaptation of the methodology to the existing inventory system and training of the personnel. Following the successful demonstration, the Alberta Forestry Service adopted the LSP methodology in its forest inventory procedure.

CCRS/National Capital Commission Dutch Elm Disease Project. The spread of Dutch Elm Disease and consequent death of thousands of large elms is a costly problem in urban areas of eastern Canada. In the National Capital area, the National Capital Commission (NCC) has had a Dutch elm disease control program for the past thirty years. As an extension of this program, the NCC cooperated with CCRS in evaluating the feasibility of monitoring stress in white elms (Ulmus americana L.). Colour infrared aerial photography was contracted by NCC from a local air survey company with CCRS providing the specifications and quality control. The ground surveys were conducted by the NCC. An interpretation key was developed to assess the degree of damage. Photointerpretation and subsequent data analysis were conducted jointly by personnel from both agencies. Although the project is not completed, it appears that the results will not be sufficiently accurate to be useful for the NCC because of the intensive nature of their control program. This program is carried out over relatively small but critically visible areas and demands an early and reliable detection of disease. On the other hand, the technique may be appropriate for less intensive control programs conducted over a whole city.

Introduction of supplemental aerial photography into forestry operations in Ontario. The use of 35 mm photography is becoming more widespread in forest operations (Zsilinszky et al (1979). The techniques were developed during the 1960's and early 1970's in Ontario and demonstrated to senior field personnel. Subsequently, district offices proceeded to acquire the necessary experiment and to arrange for personnel training. Regular training courses have been offered by the Ontario Centre for Remote Sensing for several years. At the present time, 26 of the 48 forest districts utilize supplemental photography in their operations. Information on cutovers, recent burns, new roads, regeneration and site preparation are routinely mapped in this manner.

The Ontario Centre for Remote Sensing (1975) has also introduced mapping of forest fire burns from Landsat data and has been actively involved in developing methodology for forest inventory based on satellite imagery (Zsilinszky and Pala, 1977). As a provincial government agency, the Centre cooperates closely with various forestry agencies in Ontario.

Use of satellite data for updating Nova Scotia forest inventory. In Nova Scotia, where forestry products are the largest single export commodity, the Department of Lands and Forests is in the process of incorporating Landsat as a data source for monitoring forest dynamics on a province-wide basis. Initial discussions between professionals of this department and CCRS were followed by two years of joint experimentation aimed at developing methods appropriate to both the forest conditions and the agency. The status of individual applications is given in Table 1. While the mapping of each of these phenomena has limitations, the convenience, economy and accuracy provided by Landsat analysis has encouraged the Department of Lands and Forests to incorporate this technology into its routine forest management operations. A province-wide Landsat coverage from 1977 will be used as the baseline for monitoring forest changes.

4. SUMMARY

Significant progress in the development of applications of remotely sensed data to forest inventory and management in Canada has occurred in the last decade. The process of transferring these developments to operational use occurs through interaction of the developers of the methodologies and the potential adopters. In Canada, two primary mechanisms for promoting this type of interaction may be distinguished: user liaison and joint projects. Cooperation and commitment are the key elements of both. These efforts will permit to obtain economic and social benefits from the applications of remotely sensed data.

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