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FOREST CLEARCUT MAPPING IN NORTHERN ONTARIO.
USING LANDSAT THEMATIC MAPPER IMAGERY:
A USER-ORIENTED APPROACH

by

ANTHONY MICHAEL TURNER, B.Sc.

A Thesis submitted to
the Faculty of Graduate Studies and Research
in partial fulfillment of
the requirements for the degree of
Master of Arts
Department of Geography

Carleton University

Ottawa, Ontario

September 15, 1988

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September, 1988

ABSTRACT

An approach to mapping clearcuts using LANDSAT imagery was developed by addressing the requirements of district and industry foresters in northern Ontario. A survey revealed the widespread use of 35 mm supplementary photography for mapping clearcuts. As well, the reporting practices, related uses for the data and experience with LANDSAT imagery were solicited. Using an optical transfer device (Procom-2) and a visual interpretation of a LANDSAT Thematic Mapper imagery (bands 1, 2 and 3), clearcuts were mapped on a 1:15,840 Forest Resources Inventory map of Pelletier township. Using a Geographic Information System (SPANS), results were compared with the conventional method using 1:50,000 photography as a reference. The results showed that Thematic Mapper imagery produces similar levels of classification accuracy except for small clearcuts and somewhat better results for positioning of cuts. By comparing these and other requirements of foresters, it was found that Thematic Mapper imagery is 88% as effective as supplementary photography and could be used as a supplement to this latter method.

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Forest Clearcut Mapping in Northern Ontario
Using LANDSAT Thematic Mapper Imagery:
A User-Oriented Approach

CHAPTER 1

INTRODUCTION

1.1 Introduction

There is little doubt that the proper management of Canadian forests is one of the most important issues facing the forest industry in Canada today. Both government and private authorities have recognized that if Canada is to have enough wood for future generations it must act now with better forest management practices (Environment Canada, 1981, Science Council of Canada, 1983, Canadian Institute of Forestry, 1984). Clearly, the continued viability of Canadian forests and forestry hinges upon the continued development and implementation of innovative and sound forest management practices.

One aspect of forest management is the monitoring of timber harvests and other depletions. Not only does routine monitoring help determine the location and rate of

depletion of merchantable stands of timber but it also helps foresters to assess the quantity, quality and accessibility of the remaining timber supply. Furthermore, the information derived from forest depletion monitoring is useful for planning forest renewal and harvesting. In addition to these operational uses, the depletion information gathered provincially is used by the Canadian Forestry Service in order to obtain a national overview of the state of Canadian forests.

Forest monitoring has been carried out with varying degrees of regularity and levels of success by the agencies entrusted with the responsibility for the management of Canada's forested lands. These groups are provincial forestry departments, or, in the case of the territories and federal lands, primarily the departments of Indian and Northern Affairs, National Defence and Transport. Besides government agencies, logging companies are increasingly sharing the responsibility for developing and implementing monitoring procedures within the general framework of forest management agreements. These agreements are now common in several provinces including British Columbia, Ontario and New Brunswick (Fullerton, 1984, Watson, 1984).

There is considerable variation between the provinces in the method of monitoring, mapping, regularity of monitoring and reliability of the statistics acquired on land that is lost from the forest inventory land base.

Some provinces use ground surveys or sketch mapping from light aircraft. Others may use survey photography or supplementary photography. Since methods vary, the statistics gathered on the various attributes of harvested lands can be difficult to compile and compare to obtain a national perspective on the state of the nation's forests (e.g., Bonnor, 1982).

Modern satellite technology provides an alternative data source that contains information on many types of changes in the forest environment. Soon after the launch of LANDSAT 1 in 1972 it was recognized that its sensors could detect features useful for various requirements of forest inventory, in particular the detection and mapping of forest clearcuts (Sayn-Wittgenstein and Wightman, 1975).

Although satellite images have been available since 1972, the methodologies developed to obtain useful information about the changing forest environment have not, with the exception of a few cases, passed from the hands of researchers to the operational forester. British Columbia stands out as the leader in the operational utilization of LANDSAT for a portion of their forest harvest mapping (Heygi and Quenet, 1981). Other provincial and territorial agencies, as well as forestry companies, have yet to adopt the technology in other than an experimental capacity. Clearly there is a need to determine why such a situation exists.

1

Although there is an extensive body of technical knowledge on the capability of LANDSAT for monitoring forest depletions, it is not clear why the adoption of the LANDSAT imagery has not yet reached its full potential in the forestry sector. The fact that the diffusion of new technology such as LANDSAT imagery takes some time to replace or supplement an established methodology is one factor. It is also reasonable to speculate that there may be other reasons why an apparently useful and cost-effective technology has not been widely used by the forestry sector. Some possible reasons include the following:

- (1) there may be cartographic and resource mapping limitations of LANDSAT imagery that have not been fully brought to light.
- (2) the technical requirements of the foresters may not have been fully explored and reconciled with the technical capability of the LANDSAT imagery.
- (3) there may be economic, administrative or other constraints acting on the forestry sector that limit its ability to adopt a new technique.

It is against this background that this thesis is being undertaken. The technical capability of LANDSAT imagery for mapping forest depletions needs to be examined in light of the requirements of foresters.

1.2 Objective

The objective of this study is to develop and analyze a method of monitoring and mapping forest clearcuts using LANDSAT imagery and compare it to the existing methodology in terms of the technical and other factors important to the foresters who presently monitor forest changes.

Although it is recognized that clearcuts are but one type of forest depletion, they represent a major type of timber loss occurring in the boreal forests of Canada. Along with fires, harvest operations by clearcutting are responsible for the largest, most dramatic and swiftest changes in the forest environment.

1.3 Approach

In order to achieve a comprehensive examination of this subject, an approach that tests the effectiveness of monitoring forest depletions using LANDSAT imagery against the background of critical requirements of foresters is necessary. The approach to this problem, therefore, has two phases. The first is to establish the technical requirements of the forestry sector regarding forest depletion monitoring and mapping. In addition, this phase entails an examination of the present methods of conducting clearcut mapping. Economic, logistical, administrative and other factors affecting the forestry sector are also considered.

The second phase of the approach is to map forest clearcuts using LANDSAT Thematic Mapper imagery and compare the results with those obtained by conventional means. The results of the analysis can then be discussed along with other factors to arrive at an overall assessment of the suitability of LANDSAT imagery for detecting and mapping clearcuts. The end result will be an all-encompassing comparison of the new technique with the conventional technique.

Such an approach takes into consideration the fact that foresters presently use a particular type of remotely sensed imagery. Therefore, it is against this conventional technology that a new "competing" technology must be measured. It is for this reason that the approach is considered user-oriented. If the method of using LANDSAT developed within this thesis is accurately assessed, the key strengths and shortcomings of using LANDSAT for mapping clearcuts will come to light. Also, this study may point to the most readily acceptable means by which satellite remote sensing can be used for this application.

1.4 Technology and Technological Substitution

This thesis is the study of an alternative source of remote sensing data within the broad context of the organizations that stand to benefit from its adoption. Therefore, it is important not only to examine the technology

and technical merits of one technique over another, but also to understand how technologies are believed to compete and what factors influence the substitution of one technology for another.

Technology may be simply defined as the way something is done. It is composed of several components, of which one may be machinery. Some authors have argued that technology, especially as perceived in the age of high technology, has become almost synonymous with machines when know-how or knowledge is, perhaps, a more universal component (Macdonald, 1983). For example, newly adopted practices such as crop rotation may not always be viewed as technological change but such new practices represent some of the most profound and successful examples of technological change that do not involve machines. Therefore, to achieve a successful substitution of a new technology, the correct approach is, first, to define accurately the problem of the potential adopter in terms of the knowledge he requires, rather than assuming that new technological "machines" will be an essential part of the solution. A second principle is that the proposed substitute technology should be flexible enough to accommodate the greatest number of requirements of the user.

While the analysis of technology and technological substitution is usually applied to industrial processes and consumer products (e.g., Blackman, 1976), the factors

considered important in these studies should have equal relevance to competing remotely sensed data sources and techniques. For example, alternate technologies compete on the basis of a number of economic factors such as price and utility (Sahal, 1981). As well, the market occupied by the new technology may often be slightly different from the market of the existing technology. Finally, attitudes of users and their knowledge of new technologies will influence the speed and success of the substitution. These aforementioned factors will surely apply to such competing technologies as LANDSAT and conventional remotely sensed image sources. In other words, the study of LANDSAT as a technological rival will also be a study of those factors which are associated with the competing technologies.

1.5 Limitations

Although this study is essentially a holistic study, many of the topics touched upon will not be examined as closely as others. Rather, this study will concentrate on those aspects viewed as important from the standpoint of the foresters as well as those which are more easily quantified. Economic and administrative requirements and constraints of foresters, while touched upon, will not be explored in detail. Since this thesis is limited to forest clearcutting, a working definition of clearcutting as the harvesting of all merchantable timber from an area of

forested land will be used. The technical comparison of the remotely sensed imagery to map clearcuts will be done using means available to the author and may not represent the optimum way to compare such data.

1.6 Research Methods

Because of gaps in published literature on the requirements of the forestry sector operating in northern Ontario, a questionnaire was devised and sent to government and industry foresters. The survey enabled a more complete picture of the forest sector to be obtained. For example, the methods used and requirements for clearcut mapping were solicited. Furthermore, other information such as time frames for data acquisition, relevant statistics compiled and attitudes of foresters to the new technology could also be determined.

An appropriate method for mapping clearcuts using LANDSAT Thematic Mapper imagery was selected from a number of approaches which have been used for mapping and measuring man-made changes both within and outside the forest resource sector. This technique is compared to the conventional technique of mapping clearcuts using a typical township in northern Ontario as a test area.

CHAPTER 2

THE FOREST INDUSTRY AND CLEARCUT MAPPING IN NORTHERN ONTARIO

2.1 Introduction

A study of the substitution of one technology for another necessitates an understanding of the "users" of that technology. In the context of this study it is therefore necessary to construct a profile of the forest industry in northern Ontario. In doing so, particular attention will be paid to the technical requirements of foresters regarding clearcut mapping. In addition, other considerations such as price, methodology and attitudes and knowledge of LANDSAT imagery need to be explored. This profile will form the basis for a comparison of LANDSAT imagery with the conventional data sources.

2.2 Forest Regions of Ontario

The forests of Ontario fall into four broad regions (Rowe, 1972, Figure 2-1). Three of these forest regions are found in northern Ontario. The Great Lakes-St. Lawrence region is the most southerly zone. This zone is primarily a mixed forest region with the characteristic species being Pinus resinosa (red pine), Pinus strobus (white pine), Tsuga canadensis (eastern hemlock), Betula

Figure 2-1. Forest Regions of Ontario (after Rowe, 1972)

alleghaniensis (yellow birch) and Acer saccharum (sugar maple). Most of the timber in this region is used for the manufacture of lumber, quality veneer and furniture (Ontario Ministry of Natural Resources, 1986).

Lying to the north is the boreal forest region which is composed primarily of softwood species, of which Pinus banksiana (jack pine) and Picea mariana (black spruce) are the most commercially important. Betula papyrifera (white birch) Populus tremuloides (trembling aspen) and Abies balsamifera (balsam fir) are also common throughout this region. The chief uses of wood from this region are pulp and paper and lumber.

Further to the north, occupying the Hudson Bay Lowlands is a forest and barren subregion of the boreal forest. In this zone Picea glauca (white spruce), Picea mariana (black spruce) and Larix laricina (tamarack) are the dominant species. However, the trees of this region are not considered economically viable for forestry purposes due to the poor volume of timber per unit area and the remoteness of the region from mills and markets.

2.3 Economic Importance of Forestry

The forest industry represents an important sector in a province dominated by manufacturing. About 2.3% of the gross provincial product, which represents the total of all economic activity in the province, is contributed directly

by the forest industry (Ontario Ministry of Natural Resources, 1981). The forest industry is particularly important in the economy of northern Ontario. As much as 70% of the economy of some regions such as northeastern Ontario are dependent upon the forest industry. As well, many towns depend almost entirely upon the forest for their economic survival. Therefore, any efforts that improve the management of the forest resources of northern Ontario will also have an impact on its future economic well-being.

2.4 Forest Management in Ontario

The forests of Ontario are managed through a hierarchical administrative system. At the top of the hierarchy is the Forest Resources Group of the Ontario Ministry of Natural Resources, located in Toronto. Reporting directly to this Group are eight regional offices, half of which are located in northern Ontario. The regions are divided into management districts of which there are 69 in the province. Northern Ontario contains 24 such districts each having several forest management units.

While the ultimate responsibility for the management of forested land in Ontario lies with the provincial government, over the course of this century the operational management of these lands has shifted between the Government of Ontario and the private forestry companies (Fullerton, 1984). Presently, the Ontario Ministry of

Natural Resources administers the Crown forested lands of Ontario, but the role of private industry is becoming increasingly more important. Since 1980, the government has gradually turned over the responsibility of forest management to industry (Fullerton, 1984). The rationale for this policy is that logging companies will become more responsible guardians of a license area should they be given long-term (20 year) tenure on the property. Under the agreements, companies are responsible for harvesting and regeneration of the forest on a sustained yield basis, while also providing a continuous supply of harvested timber for their needs (Ontario Ministry of Natural Resources, 1985). This contrasts with the previous situation in which industry was responsible for little more than activities related to the harvesting of the resource.

With respect to harvest operations, a company entering into a Forest Management Agreement (FMA) with the provincial government is required to prepare and submit forest management plans for the 20 year period, operating plans at five-year intervals and annual plans and reports (Ontario Ministry of Natural Resources, 1985). One aspect of the annual report is stated in the current Crown Timber Act (1980) as follows:

not later than the 31st day of October in each year a map showing the boundaries and acreage of the areas cut over and the parts thereof that were not cut during the twelve month period

ending on the 31st day of March of that year together with a statement of the acreages of the areas cut over the parts thereof not cut and the amount, species and size of timber cut from each cutting area during such period.

Crown Timber Act R.S.O., 1980 Sec. 27 (1) (b)
(Ontario, 1984)

For forested areas outside the jurisdiction of the FMA license holders, the Ontario Ministry of Natural Resources district offices are responsible for collecting, updating and reporting depletions on an annual basis. Some district foresters also check the information supplied by the FMA license holders within their district.

2.5 The Forest Resources Inventory System

The forested land in Ontario is classified using a detailed system of mapping called the Forest Resources Inventory (FRI). The inventory covers approximately 61.6 million hectares of Ontario (Ontario Ministry of Natural Resources, 1978). However, when water, non-forested land, withdrawals and otherwise non-productive land are excluded, about 40 million hectares of productive forested land remain. A further 2.1 million hectares of forested land are classified as protection forest because of their importance in maintaining the ecological balance and aesthetic qualities of the overall landscape. About 34.5 million hectares or 86.5% of productive forest land of

Ontario lie within the four administrative regions of northern Ontario. The FRI maps do not extend to the far north of the province. The unmapped area corresponds roughly to the sparse forests of the remote northern Hudson Bay Lowland region.

The Forest Resources Inventory is useful to foresters and other resource managers because it provides a detailed description of the forested land base. As such, the inventory provides a valuable tool for decision making and planning for uses such as access, silviculture and forest protection (Ontario Ministry of Natural Resources, 1986). Other resource managers, including wildlife, land use and fire managers also make extensive use of the inventory for their particular requirements.

2.5.1 Mapping Procedure

Forest Resources Inventory information is compiled and mapped at 20 year intervals. The maps are made through a process which lasts three years (Ontario Ministry of Natural Resources, 1978). During the first year, large scale black and white photographs of the area are obtained. The following year, sample plots are inventoried by ground crews at a density of about 1 per 2.6 km² (1 per square mile). Individual forest stands are defined on the basis of the uniformity of a stand for a number of key attributes. These attributes include stand composition,

age, height, and stocking and site conditions of the working group. The working group is defined as an "aggregate of stands...having the same predominant species and managed under the same rotation and broad silviculture system" (Ontario Ministry of Natural Resources, 1986:110). Finally, during the third year, the forest stand information is validated and maps and reports are produced. Forest stand maps having a scale of 1:15,840 are the primary product. As well, composite maps at a scale of 1:50,000 and ledgers are compiled on a management unit basis.

2.5.2 Revision Procedure

Although every twenty years the FRI maps are scheduled for complete revision using newly acquired survey photography, significant changes that take place during the intervening years must be monitored. Changes due to harvesting, fires and other causes must be integrated with respect to the inventory information in order to facilitate effective management of the resource.

In order to fulfill this need, supplementary aerial photography (often called SAP) was introduced by the Ontario Department of Lands and Forests (now the Ministry of Natural Resources) in 1968 (Zsilinszky et al., 1979). Supplementary photography was proposed as an effective method for obtaining useful map revision information for

several reasons. The resolution was considered adequate to map the linear boundaries of clearcuts, burns and roads and other major depletions to the forest environment.

(Zsilinszky, 1968). Additional uses for the photography include the monitoring of regeneration and the preparation of sites for regeneration. Other major advantages of such a method of supplementary photography are outlined below:

- (1) the low cost of equipment and processing
- (2) the availability of Ministry aircraft
- (3) the feasibility of training field technicians in the operational procedures.
- (4), the piecemeal photography needed would not be profitable for aerial survey companies.

(Zsilinszky et al., 1979)

The 35 mm format photography is acquired using Ministry of Natural Resources aircraft equipped with specialized camera ports and apparatus for mounting the camera. As of 1979, 26 district offices, primarily in northern Ontario were using the supplementary photography for cutover, burn and road detection (Zsilinszky et al., 1979).

2.6 Profile of Northern Ontario Foresters

While the revision procedure for FRI maps outlined

above is used extensively in all parts of Ontario, it would be useful to examine specific details of the method as used in northern Ontario. In addition, the attitudes and knowledge of foresters about LANDSAT imagery as it might be applied to clearcut mapping can also be explored.

In order to obtain such information, a survey was conducted. A total of 26 government district offices of the Ontario Ministry of Natural Resources and 14 logging companies with established Forest Management Agreements with the provincial government were surveyed. Of the 40 functional units surveyed, 36 replies were received. Twenty-two of the returns were from district offices of the Ontario Ministry of Natural Resources, while all of the 14 logging companies replied. One Ministry district office in Moosonee claimed to have no forestry activities within its jurisdiction and therefore did not complete the questionnaire. Therefore, a total of 35 responses formed the basis of the information compiled below. The questionnaire and the tabulated results can be found in Appendix A.

The geographic extent of management responsibility of each of the government and industry respondents is shown in Figures 2-2 and 2-3 respectively. The area of overlap between government and industry occurs because the Ministry of Natural Resources has ultimate administrative authority and other responsibilities in management of lands under

Figure 2-2. Area under management or administrative control
by Ontario Ministry of Natural Resources respondents

Figure 2-3: Area under management by private logging company respondents

Forest Management Agreement with industry. For example, regarding clearcut mapping, a company may be responsible for data acquisition and mapping of clearcuts while the relevant district office may check the mapping with the same photography.

2.6.1 Technical Characteristics of Clearcut Mapping

In total, 34 of the 35 respondents directly acquire information concerning clearcut operations for their own areas of responsibility. As expected, the remotely sensed imagery used in all cases is 35 mm supplementary aerial photography (SAP). About half of the respondents supplement this data with field mapping techniques while a few (3/35) also use airborne overflights to obtain more detailed or timely information of the clearcut area.

Data for clearcut information is acquired once a year in half of the Ontario Ministry of Natural Resources districts while the others collect the information twice or more a year. Most of the forestry companies acquire the information once a year. The most favoured month for acquiring aerial photography is May, followed by June and April. However, the dates range from January to August. The date of acquisition should reflect compliance by the districts and companies with the requirement to provide maps of harvested area on a fiscal year basis (April 1 to March 31). A few respondents collect data more than once a

year, probably for internal record keeping and planning purposes not stated.

Recent clearcuts are interpreted from the supplementary aerial photography at a scale of 1:15,840. The clearcut polygons are transferred to the Forest Resources Inventory (FRI) maps either by directly mapping on the paper copy or by using mylar or chronoflex overlay material. The "Sketchmaster" optical transfer device which aids in the minor adjustment of photographic scales, is used by 31 of the 35 respondents to transfer the change information from photography to map. Other devices used are enlarger-reducers and an "Artograph" which is similar in function to the "Sketchmaster".

As stated in Section 27 of the Crown Timber Act, various types of spatial and statistical information are required to be reported to the head office of the Ministry of Natural Resources by FMA license holders (Ontario, 1984). Most significant is a map showing the area of harvest for the previous fiscal year. Other information such as the species and volume depleted is also reported, but may not necessarily be obtained from the remote sensing data. This information may be derived from the FRI maps or obtained from statistics kept from harvesting operations.

Positional or cartographic accuracy requirements were asked of foresters since the mapping of clearcuts is not used to its optimal advantage unless the spatial extent is

related to FRI information such as species, height, age and volume. There is no standard positional accuracy requirement for mapping from supplementary photography. According to 15 respondents to the questionnaire, the positional accuracy of their mapping varies widely in the perception of the foresters (from 1 m to 150 m).

One important advantage of supplementary aerial photography which may negatively influence the acceptance of an alternative remotely sensed image source, is the usefulness of the photography for secondary purposes. For example, it was found from the survey that the majority of foresters also use the supplementary photography for a variety of related purposes. The mapping of access roads and fire damage areas, partial cutting and the monitoring of regeneration areas are common secondary uses. The photography is also used for planning purposes such as planning for seeding, site preparation and future cutting operations.

Regarding partial cutting, most respondents (29/35) stated that this represents less than 30% of the total area of clearcutting within their jurisdiction. Generally, more partial cutting occurs in southerly districts which fall within the Great Lakes-St. Lawrence forest region. This forest region offers the diversity of species for the harvesting of selective timber.

The cost of acquiring supplementary photography is

useful to know since a competing data source will have inherent costs that may impede or hasten its use as a replacement of the conventional method. In terms of cost of acquiring supplementary photography, most respondents (29/35) spend less than \$5000.00 per year. The real cost is likely higher than \$5000.00 since the costs of planning photographic coverage and associated overhead costs were probably not considered by the respondents. On average, however, companies tend to spend more than Ontario Ministry of Natural Resources districts. This may be due to the added costs of contracting out for the aircraft used for gathering the supplementary photography. The district offices use government aircraft at times when the planes are not needed for more urgent purposes such as fire patrol (Zsilinszky et al., 1979).

2.6.2 Familiarity with LANDSAT Imagery

Experience with and attitudes to LANDSAT imagery on the part of the respondents revealed some interesting findings. Thirty-four out of 35 districts and companies had never used LANDSAT images for mapping clearcuts although about half of the 34 had considered using the information source. The most commonly cited reasons for not using LANDSAT are:

- (1) they need to acquire the supplementary photography for other purposes anyway (16/34).

- (2) they are satisfied with the present method of mapping clearcuts (16/34).
- (3) the lack of a capability to integrate the results with the FRI (forest stand) maps (14/34).

Other responses showed that at least one quarter of the respondents had insufficient knowledge of LANDSAT images, their information content and the techniques of analyzing the images.

Despite the lack of current use of LANDSAT images, a large majority of district and company foresters (31/35) stated that they would consider the use of LANDSAT imagery as a supplement to aerial photography should they be shown that forest clearcuts could be mapped as accurately, completely and as ~~cost~~ effectively as their current methods. However, less than half (13/35) indicated that they would consider LANDSAT imagery as a replacement of supplementary photography. An intermediate number (24/35) stated that in certain areas under their jurisdiction they would consider replacing their present remote sensing source with LANDSAT imagery.

Although most respondents had not previously used LANDSAT imagery, the most often mentioned stipulation for its utilization for the mapping of clearcuts were accuracy, timeliness of coverage, data availability and cost-effectiveness.

2.7 Discussion

Generally, it appears that the foresters responsible for clearcut monitoring in northern Ontario are satisfied with the methodology of mapping clearcuts using supplementary 35mm photography. This remote sensing data is inexpensive to acquire, versatile, easily interpreted and the information it contains is readily capable of being transferred to the FRI base map using relatively common transfer devices.

However, the technical effectiveness of supplementary photography for its intended purpose appears difficult to ascertain. The fact that its use is so widespread in northern Ontario may indicate that it is of critical importance to the information requirements of district foresters. However, a policy directive by higher administrative officials or perhaps the lack of any practical alternatives, may also be valid reasons for its continued use. In any case, the technical effectiveness of the program in obtaining accurate information appears not to have been assessed in the literature.

If LANDSAT imagery is to be considered as an alternative to supplementary photography by the foresters presently using the latter imagery, there are several questions the profile of the forestry sector has raised that ought be considered. These are:

- (1) Can a methodology using LANDSAT imagery be integrated effectively with the Forest Resources Inventory information?
- (2) How completely and positionally accurate can clearcuts be mapped using LANDSAT imagery?
- (3) Would a technique using LANDSAT imagery also be able to monitor other changes in the forest environment that are now obtained from supplementary photography?
- (4) Can LANDSAT imagery compete with supplementary photography in terms of cost and timeliness of acquisition?
- (5) Could a technique utilizing LANDSAT imagery be easily used by those currently mapping with supplementary photography?

Some of these questions are more critical and constraining than others. Nevertheless, any technique using LANDSAT imagery should be assessed against them. Technical competence is the most important criterion. However, at some point in the assessment of an alternative or additional remotely sensed image source, several of these other questions will have to be addressed.

CHAPTER 3

APPLICATIONS OF LANDSAT IMAGERY TO FOREST CLEARCUTTING

3.1 Introduction

Having investigated the present use of supplementary photography for mapping clearcuts in northern Ontario, it is now important to investigate research into remotely sensed data from LANDSAT. The purpose of this chapter is to examine the capabilities of LANDSAT imagery for monitoring clearcuts. Attention will be given primarily to the technical capacity of LANDSAT imagery including a review of the different methods of analysis used to monitor clearcuts. An underlying purpose of the review is to determine how well these techniques could meet the requirements of foresters as found from the profile of the forest industry in northern Ontario outlined in Chapter 2.

3.2 Description of LANDSAT

LANDSAT was the first unmanned satellite specifically designed to acquire data about earth resources on a systematic basis. Since 1972, the imaging systems aboard successive LANDSAT missions have offered the advantages of multispectral and medium resolution imagery covering large areas on a repetitive basis. The current LANDSAT satellites (numbers 4 and 5) are orbiting at about 900 km

above the earth every 103 minutes (Estes et al., 1983). The satellite travels in a near-polar orbit that allows data to be recorded to within 9 degrees of the poles.

The orbit of LANDSAT has several features that enable a unique view of the earth to be captured. The orbit is sun-synchronous and developed in such a way that the ground is imaged at the same local time of 9:30 every 16 days. In mid and northern latitudes there is considerable overlap between adjacent tracks resulting in potential repeat coverage every 8 days. The area recorded on one scene is 185 km by 185 km or 34,225 km². Every place on earth except the extreme north and south polar regions has the potential to be recorded at least 22 times per year.

Currently, there are two imaging devices aboard the operational LANDSAT satellites; the multispectral scanner (MSS) and the Thematic Mapper (TM). Each sensor has different spectral, radiometric and spatial properties. The characteristics of the Thematic Mapper and multispectral scanner are summarized in Table 3-1. The multispectral scanner scans a scene from west to east as the satellite tracks north to south. The scanner records reflected radiation in two spectral bands in the visible portion of the spectrum and two others in the reflected infrared portion of the spectrum. Each ground picture element or pixel is 79 m by 79 m but due to sampling of the output of the detectors the nominal ground resolution is

56 m by 79 m. The data for each of the four spectral bands are stored as a digital number ranging from 0 to 63 thereby giving a radiometric resolution of 64.

<u>SENSOR</u>	<u>BAND</u>	<u>SPECTRAL RANGE</u> (nanometers)		<u>RADIOMETRIC RESOLUTION</u>	<u>SPATIAL RESOLUTION</u> (meters)
MSS	1 or 4	.5-.6	VIS green	64	79
MSS	2 or 5	.6-.7	VIS yellow	64	79
MSS	3 or 6	.7-.8	RIR	64	79
MSS	4 or 7	.8-1.1	RIR	64	79
TM	1	.45-.52	VIS blue	256	30
TM	2	.52-.60	VIS green	256	30
TM	3	.63-.69	VIS red	256	30
TM	4	.76-.90	RIR	256	30
TM	5	1.55-1.75	RIR	256	30
TM	6	10.40-12.50	TIR	256	120
TM	7	2.08-2.35	RIR	256	30

Table 3.1 Sensor characteristics of LANDSAT multispectral scanner (MSS) and Thematic Mapper (TM). Spectral ranges refer to visible (VIS), reflected infrared (RIR), and thermal infrared (TIR). (Estes *et al.*, 1983) Second MSS band numbers refer to those used for LANDSAT 1, 2 and 3.

The digital data are telemetered to earth receiving stations where they are recorded on digital tapes. The data undergo standard corrections for geometry and radiometry and are copied onto computer compatible tapes for those users who wish to do digital image analysis. They can also be processed into photographic products for those who wish to undertake visual image analysis.

The Thematic Mapper sensor represents a significant improved capability over the multispectral scanner sensor

in spectral, spatial and radiometric characteristics. The Thematic Mapper sensor contains seven spectral bands, three visible, two reflected infrared and one thermal infrared. The spatial resolution of each of the TM bands is 30 m except for the thermal band which is 100 m. The 30 m spatial resolution is a substantial improvement over the 79 m for the MSS. The radiometric resolution is also improved from the 64 levels of the MSS to 256 levels for the TM. These advances have produced greater spectral and spatial detail of the earth but have also created correspondingly greater data storage and processing problems due to the volume of data.

3.3 Forestry Applications of LANDSAT Imagery

Satellite remote sensing was recognized as having a promising potential for forestry resource management long before the first LANDSAT satellite was launched in 1972. For example, infrared sensors aboard meteorological satellites generated data that could be used to separate broad regions of predominantly hardwood, softwood and non-forested land (Aldred, 1968). Moreover, the broad view and repetitive coverage afforded by satellite observation was seen to be of great potential benefit for observing forest and land interactions in addition to detecting changes such as insect and fire damage.

During the early years of the LANDSAT program, it

became clear that much information important to foresters was contained in the data. A summary of the earliest operational capabilities of LANDSAT multispectral scanner data for forestry applications in Canada was found to be limited to the mapping of recent forest fires, broad forest cover types and as one component of integrated resource surveys (Sayn-Wittgenstein and Wightman, 1975). Cutover detection and mapping proved successful for small research areas, but extension to larger regions had not yet been done. Monitoring the growth patterns of various tree species had not been successful, but experiments in detecting insect damage, floods, and wind damage had shown promise. However, standardized analysis techniques had not yet been developed. Although most studies of LANDSAT had utilized visual interpretation techniques, digital analysis methods were thought to be the most promising.

A more recent review of satellite remote sensing applications in forestry with particular emphasis on the Thematic Mapper sensor has shown that changes to spatial, spectral and radiometric resolutions have improved the discrimination of features in the forest environment (Benson and DeGloria, 1985). For example, a general improvement has been identified in the detection of grassland, brush and hardwood/conifer mixed forest. It has also been discovered that the addition of TM band 5 in the middle infrared region of the spectrum aids in the dis-

crimination of forest damage and mortality and improves the detection of general forest types (Ahern and Archibald, 1986; Benson and DeGloria, 1985; Horler and Ahern, 1986).

3.4 Forest Clearcut Monitoring Using LANDSAT Imagery

Forest clearcut detection using LANDSAT images has been applied to both hardwood and softwood environments. Since the tree cover in northern Ontario is predominantly softwood, only the literature pertaining to similar cover types will be examined.

Attempts to map and monitor clearcuts using LANDSAT data have been made since the early 1970's. Varying degrees of success have been achieved depending on the method employed and factors relating to the characteristics of harvesting operations in a particular area. In general, the procedures can be divided into digital, or computer-aided, techniques and visual, or photointerpretation, techniques.

3.4.1 Digital Techniques

The detection of forest using digital interpretation techniques represent the most common means found in the literature. Digital techniques may be divided into two kinds: those that classify one date of image and those that utilize two or more dates of imagery.

Generally, digital analysis techniques make use of

either unsupervised or supervised classifications. In an unsupervised classification the radiometric or grey levels of the digital image are separated into several groupings on the basis of the statistical distribution of spectral and/or spatial characteristics (Hajic and Simonett, 1976). Several types of statistical relationship may be used. The most common procedure uses a clustering algorithm to separate the desired number of classes. The classes can be subsequently checked against the original data or supplementary information to determine if the separated classes match.

In contrast to unsupervised classification schemes, in supervised classifications, the desired number and type of features are first selected. Small areas where certain features are known to occur are then statistically analyzed for their spectral and radiometric characteristics. The results of the statistical relationships of these training sites form the basis of a classification of the entire image. Reliable ground data for the various classes is often obtained in order to verify the reliability of the supervised classification.

3.4.1.1 Single Date Approach

In order to use a single digital LANDSAT image for clearcut detection, two general strategies are commonly followed. In the first case, the entire image is clas-

sified with clearcuts being one of the classification units (themes). In the second case, only the clearcuts are identified to the exclusion of all other features contained in the data. In either case, the spectral and radiometric characteristics of clearcuts must be sufficiently distinctive so that they can be extracted from the data with a minimum of confusion with features with similar spectral reflectance. The identification of each of the image classes can be determined by performing either unsupervised or supervised classification of the spectral information contained within the scene.

Benefits of single image classifications are that geometric corrections and registration of multiple images are not necessary. Also, since only one image of the area need be purchased, data acquisition costs are reduced. Finally, the necessity of acquiring two cloud-free images over a specific time frame is eliminated.

The major problem with single image classification is that it presents a view of the forest at a particular time. As a result, rates of change of clearcuts cannot be obtained except through a comparison with subsequent image classification or with an out-of-date forest inventory map.

The usable product of a single image classification may be a digital map, paper map, or the classified image itself. In most of the cited research, a classified image and statistics generated from that classification were the

final products. In attempts to use single image classification in operational mapping, it has been demonstrated that the classification may be integrated with a digital forest inventory database (Hegyí and Quenet, 1983). This provides the forester with a more useful product. The printing of classifications of clearcuts at large scales has also been mentioned as being feasible (Jano and Pala, 1984). Presumably, a print of a classification suitable for overlaying on to a forest inventory map could be prepared.

The various ages of clearcuts have presented classification problems in several single image studies.

For example, according to a study in New Hampshire, ages of clearcuts and stages of regrowth may cause spectral characteristics to vary widely (Bryant et al., 1979). This study showed that several spectral signatures may need to be developed for clearcuts in order that the various stages of regrowth are correctly classified as cut. In a boreal forest setting in Manitoba, classification of older clearcuts proved difficult because deciduous shrubs within the regrowth areas and uncut mature hardwood stands exhibited similar spectral characteristics (Dixon et al., 1984). This spectral confusion resulted in lower classification accuracies for older clearcuts.

Adding to the difficulty of separating mature and young deciduous growth is the fact that deciduous trees are

often intentionally left uncut within clearcuts. Some of these stands may be large enough to be classified as uncut polygons during the classification process. However, these areas are considered cut, from a forestry standpoint, since the timber left standing such as poplar, is often considered unmerchantable (Lee and Lui, 1979).

Single date classifications can also produce considerable confusion between clearcuts and other cover types. In Manitoba, besides the mature deciduous forest mentioned previously, marsh and some jackpine areas were incorrectly classified as clearcuts (Dixon et al., 1984). A similar confusion was noted in Maine where it was found that the spectral overlap of clearcuts, bogs and roads can cause significant classification errors (Woodwell et al., 1983).

Despite the limitations of using a single image for classification, several studies have yielded reasonable results. Forest clearcuts as small as 3 ha were identified in northern New Hampshire (Bryant et al., 1979). Using a supervised classification, 73% of clearcuts were correctly classified in a lowland environment in Manitoba (Dixon et al., 1984). Hardwood forest was the prime source of confusion. In a Precambrian setting the classification accuracy improved to 98%. In Saskatchewan, classification accuracies between 32 and 96% were achieved compared with the areas mapped as clearcuts on forest resource maps (Lee and Lui, 1979). The range of accuracy is partly explained

by the foresters who employed a wider definition of what constituted a clearcut in the map compilation process by including unmerchantable stands of timber.

3.4.1.2 Multiple Date Approach

Multiple date approaches to the delineation of forest clearcuts attempt to emphasize the spectral differences between two LANDSAT scenes rather than trying to classify all the spectral variability of a single scene. The rationale behind multirate classification techniques is that the spectral and radiometric characteristics of pre-cut and post-cut land are strikingly different. If two images are registered, the differences should be easily recognizable and far more dramatic than most natural changes over the same time period. Such an approach does not necessitate the classification of all the cover types contained within an image and therefore eliminates the potential for the spectral overlap of image features as found in single date classifications.

One method of multirate change detection is to use a so-called vegetation index difference. In this method, the multispectral scanner bands 5 and 7 are compared through a mathematical relationship that measures the differences in spectral reflectances of features contained within the imagery. An advantage of this approach is that changes are quite easily identified even to the sub-pixel level

(Woodwell et al., 1983).

This method of band comparison has been found to be impractical for detection of clearcutting over longer periods of time (Banner and Lynham, 1981). The rapid growth of grasses and other vegetation within the clearcut area on the post-cut scene causes a reduction in the vegetation index ratio between the two images. However, this method may have application shortly after harvest before vegetation has begun to reestablish itself. A more successful method of multirate change detection has been to compare multispectral scanner band 5 (.6-.7 nm) images from two different years (Woodwell et al., 1983; Banner and Lynham, 1981; Rencz, 1985).

The classification accuracy using multitemporal imagery has been found to be quite high in numerous studies. In a coniferous environment studied in Nova Scotia it was found that the area classified as clearcuts was 10.8% less using multitemporal LANDSAT imagery than on colour infrared photographs (Rencz, 1985). Most of these omissions were small cutovers less than 1.5 ha and therefore below the detection capability of the technique. In an Ontario example, 91% of the area of clearcuts was detected using multispectral scanner band 6 (.7-.8 nm) ratio comparisons of five images over a seven year period (Jano and Pala, 1984). Rosengreen (1979) used multispectral scanner band 5 (.6-.7 nm) comparisons to map the

areas of clearcuts to within 7% of that found using orthophotographs and aerial photography for a study site in Sweden. He noted that cuts less than 2-4 ha had been detected. In another Swedish study that used multitemporal, band 5 ratios, the area of clearcuts was underestimated by 7.2% (Wastenson et al., 1981). All of the missed areas, however, were less than 2.3 ha in size. In a British Columbia example, a multidate digital classification was used to classify clearcuts from multispectral scanner imagery (Archibald and Ahern, 1985). For the two test sites studied, areas of clearcuts were overestimated by 4.3% and 11.3% when compared with medium scale aerial photography.

3.4.2 Visual Techniques

Conventional photointerpretation techniques applied to remote sensing products offer an alternative means to obtain information on forest clearcuts. In particular, the use of digitally prepared enhancements can help an interpreter obtain the optimal amount of spectral and radiometric information from a remotely sensed scene. For example, the use of reflecting projectors and colour additive viewers were common aids to the enlargement and combination of single and multidate bands of LANDSAT multispectral scanner images.

The primary advantages of visual interpretation over

digital image analysis include the lower cost of imagery, a closer affinity with air photo interpretation with which many foresters are familiar, and the ability to use a wider range of photointerpretation elements such as texture, pattern and association. The major disadvantage is that the spectral information is more difficult to separate precisely and objectively even with interpretation keys. Secondly, measurement of number, area and perimeter of polygons requires a second laborious process.

3.4.2.1 Single Date Approach

As with single date digital classification, single date visual approaches attempt to classify the clearcuts for one particular scene. Visual approaches to the classification of clearcuts have been accomplished by classifying clearcuts either directly on photographic images products or on maps at various scales using optical transfer devices.

The standard scale of satellite photographic products is 1:1,000,000 which is too small for delineating all but broad areas of clearcuts so photographic enlargements have been commonly used for this purpose (e.g., Woodwell, 1983). A LANDSAT image can also be enlarged and merged with a base map of a larger scale by means of an optical transfer device. Several advantages are gained by using this method. One is that geographic control of the interpre-

tation is established because changes are referenced to the map. As well, the information contained on the base map can often be used to guide the interpretation and help eliminate sources of confusion such as marshes and hardwood forests. Although this method has not been extensively applied to forestry, it has proved successful in identifying changes to topographic maps (Gregory and Moore, 1986). Many types of features contained on topographic maps are similar in geometry and spectral appearance. Using visual interpretation of the LANDSAT imagery combined with the topographic map, has enabled successful classification of new features. By using attributes of features such as texture, pattern and association with other features, a higher level classification has been found compared with interpreting an image without the aid of the map. A third advantage of interpreting a single LANDSAT image by means of an optical transfer device is that changes identified can be accurately delineated directly on the map by registering common features of the image and map during the interpretation process. Thus, a preliminary version of a revised map is created.

Accuracies comparable to digital classification techniques have been obtained using single date visual methods. In an early study area in Alberta (Winquest and Jackson, 1975), LANDSAT multispectral scanner images were enlarged to an intermediate scale for visual interpretation

purposes and then enlarged again to the desired scale of 1:63 360. Such a method produced classification accuracies greater than 97%. Map information was not used as an integral part of the interpretation.

More recently, regional foresters in British Columbia have been using 1:125,000 scale Thematic Mapper images and transferring disturbances including clearcuts to 1:50,000 regional forest inventory maps (Hilton, 1986). The results compared favorably with those obtained from 1:15,000 aerial photography. Other advantages noted were the low cost of data, low image distortion, rapidity of transfer and the uniformity of the information source.

3.4.2.2 Multiple Date Approach

The multigate approach to the visual interpretation of clearcuts is similar to the digital multigate classification in that the differences between two dates of images are compared. However, in visual interpretation, image corrections are performed optically with the aid of a map, whereas digital multigate classifications employ image transformation algorithms based on control points.

In one early study, multigate MSS band 6 images were compared using a colour additive viewer for a site in British Columbia (Lee, 1975). Areas of clearcuts that were less than 1 year old were over-estimated by 13% compared with a logging company map. Areas one year or more in age

were over-estimated by about 2%. In an unpublished report, multiple date colour multispectral scanner images were used to detect clearcuts as small as a few hectares by using a multiple image compositor (Moore and Jeffery, 1983). The images were first viewed at a small scale to identify clearcut regions. Both simultaneous and sequential viewing of the two dates of enlarged imagery with the relevant forest inventory maps were undertaken. The results were delineated directly on to 1:15,840 forest inventory maps of Manitoba. The accuracy of such mapping, where reliable ground data or maps were available, showed that most changes were correctly delineated.

Another study has shown that multirate LANDSAT multispectral scanner images can be used to map clearcuts sequentially (Murtha and Watson, 1975). In the study of an area of Vancouver Island, several dates of multispectral scanner imagery in the form of band 5 (0.6-0.7 nm) prints were used to map eight classes of clearcuts including various stages of regeneration. However, no area measurements were reported due to the lack of control of image distortion using this approach. The researchers also noted that interpreting at larger scales improved their ability to detect as well as map clearcuts.

3.4.3 Other Techniques

A recent trend in image interpretation is to make use

of the best characteristics of both digital image analysis and visual interpretation in what may be called a hybrid approach. Such an approach entails a digital classification of the spectral data that can also be readily altered by the interpreter through visual analysis of the screen image (Ryerson, pers. comm.). Ideally, a second layer of spatial information such as a digitized map should be integrated and actively incorporated in the interpretation process by providing a reference against which changes can be compared (Manore, pers. comm.). Such integration is best facilitated by the use of a geographic information system linked with the image analysis system. Based on existing publications, this approach has not yet been applied to the detection and mapping of clearcuts.

One study of clearcut monitoring has attempted to eliminate the human interpreter altogether by integrating digital maps and an artificial intelligence ("expert") analysis of remotely sensed imagery (Goldberg et al., 1985). Problems have arisen, in part associated with building in the necessary knowledge needed to make decisions about the identity of clearcuts. In addition, imperfect correlation of recent LANDSAT imagery and digital maps derived originally from subjective human interpretation has created difficulties. Therefore, features such as shores of lakes may appear as false changes when, in fact, they are differences in depiction of the same feature.

3.5 Positional Accuracy of LANDSAT Imagery

Both digital and visual approaches to detect and map clearcuts have achieved a high degree of classification accuracy. However, another consideration is the accuracy of the location of features relative to other spatial data.

This type of accuracy has been given different names in the literature, depending largely upon the remote sensing application under study. For example, in literature concerning cartographic applications of remotely sensed imagery, cartographic accuracy is the commonly used term (e.g., Welch et al., 1985). Another study has used the term positional accuracy to refer to the location of features from LANDSAT imagery relative to a topographic map (Gregory and Moore, 1986). In yet another study that concentrated on the geographic placement of clearcuts, such accuracy was referred to as displacement accuracy (Archibald and Ahern, 1985). Due to the lack of consistency in this regard, the term positional accuracy and its antonym, positional error, will be used for the remainder of this thesis.

Positional accuracy is important in any study that compares remotely sensed imagery with another set of imagery, ground reference data, maps or any other spatial information such as that found in a geographic information system. Measurement of positional accuracy is important for one main reason. The measurement of classification

errors by means of a confusion matrix or against reference data will not account for those features that have been classified correctly but are displaced relative to the reference data set. As a result, some errors of omission and commission may be, in fact, errors in the position of features relative to other spatial data. Positioning is especially important to the operational mapping of clearcuts because the changes are correlated with the forest inventory information. Thus, secondary uses of such mapping, such as calculating the species mix associated with the clearcut polygon, will not be entirely correct. Therefore, when comparing two spatial data sets, the existence of positional errors should not only be recognized as a source of error but the magnitude and location of positional errors should be determined and incorporated as part of the total assessment of accuracy.

Several investigations have determined that LANDSAT Thematic Mapper imagery has an inherent positional accuracy in the sub-pixel range. A root mean square (RMS) error of ± 25 m has been calculated for LANDSAT Thematic Mapper (Welch and Usery, 1984). This corresponds to the requirements for topographic mapping at a scale of about 1:80,000. They also state that the most significant factor that influences the rectification accuracy of LANDSAT data is the spatial resolution of the imagery. For Thematic Mapper imagery, the location of ground control points is limited

to about ± 0.5 pixel or about 15 m. In further investigations it was found that LANDSAT 4 and 5 Thematic Mapper images could meet the U.S. National Map Accuracy Standards accuracy specifications of ± 25 m for 1:50,000 topographic mapping (Welch et al., 1985, Borgenson et al., 1985).

The positioning of interpreted features in the sub-pixel range can be obtained using either digital data or photographic imagery. While some authors (e.g., Borgenson et al., 1985) contend that the standard digital remote sensing products have inherently better geometric properties than photomechanically produced analog products, the positional accuracy of features appears more a function of the method employed, rather than the type of image used. For example, offshore islands have been positioned to an accuracy of less than 1 pixel (80m) using digital LANDSAT multispectral scanner data and selecting ground control points by an automated method (Benny, 1985). Applying visual methods of interpretation to photographic products, topographic map features, including islands, have been positioned to better than ± 80 m using LANDSAT MSS (Fleming, 1977, Gregory and Moore, 1986). The use of existing topographic maps of greater accepted accuracy than the uncorrected imagery, to register new features, was an essential component of their methodology. Moreover, the latter authors have determined that as larger scales of interpretation are used, a corresponding improvement in

positional accuracy can be achieved.

Specific to forest clearcut detection and mapping, it has been discovered that positional accuracies approaching 0.5 of a pixel can be obtained (Archibald and Ahern, 1985). Photographic slides were taken of the monitor display of a digitally analyzed multispectral scanner image. The slides were then merged with forest inventory maps using an optical transfer device. The manual registration technique produced positional errors of 40-45 m, or about 1/2 pixel. The authors cite the use of the forest inventory maps as an important means of obtaining positional accuracies in the sub-pixel range.

3.6 Summary and Discussion

In summary, there is little difference between visual and digital techniques of interpreting clearcuts in terms of classification accuracy. Both have achieved accuracies greater than 90% in selected studies using LANDSAT multispectral scanner imagery where reliable ground data or maps were available. Multispectral scanner imagery could be used most reliably for clearcuts greater than 2 ha in size.

The most accurate and apparently simplest digital method of clearcut detection is the two date band 5 (.6-.7 nm) overlay. The single date photographic product combined with a suitable base map against which to map changes appears to achieve good results in topographic map revision

and apparently could achieve similar results in the mapping of clearcuts.

Regarding positional accuracies of changes, it appears that given an appropriate means to reference points or features, both digital products and standard photographic products that have not been produced from geo-coded (geographically referenced) imagery, can be used to achieve accuracies in the sub-pixel range. Thus, positional accuracy of about ± 40 m may be expected for multi-spectral scanner imagery and ± 15 m for Thematic Mapper imagery. Digital image products, especially those with geometric corrections, are inherently more correct than standard products. However, the integration of standard photographic products with a suitable map base during the mapping process can provide the control necessary to locate the features to about 0.5 pixel.

Other aspects of remote sensing imagery such as timeliness of data acquisition and integration with forestry maps have not generally been dealt with in most remote sensing literature. In general, the remote sensing research has usually aimed at demonstrating that the remotely sensed imagery contains the required information. The presentation of that information appropriate to the needs of foresters has not been addressed. Those studies that have been oriented towards the operational needs of foresters, however, do make a point of integrating the

results with forestry maps (e.g., Quenet et al., 1981, Hegyi and Quenet, 1983, Archibald and Ahern, 1985). Some others point out that maps of any scale can be produced from the digital classification (Pala, 1981, Jano and Pala, 1984), while most studies do not explain the results of their research in the context of the requirements of foresters.

3.7 Conclusion

LANDSAT imagery appears to have the characteristics necessary for the relatively complete and accurate mapping of forest clearcuts. The studies cited have used multi-spectral scanner imagery and have produced high classification accuracies using a variety of methods. Positional accuracy relative to forest inventory maps appears not to have been assessed although the positional accuracy of mapping using LANDSAT imagery for other applications suggests that ± 0.5 pixel may be attainable. It is now important to assess if any improvement in positional accuracy can be attained using Thematic Mapper imagery in the direct mapping of clearcuts at large scales. Furthermore, it should be determined if an approach of combining Thematic Mapper imagery and forest inventory information would provide any additional improvement to the mapping of forest clearcuts and be an acceptable product for operational foresters in northern Ontario.

CLEARCUT MAPPING OF PELLETIER TOWNSHIP

4.1 Introduction

Two areas of investigation have been reviewed in the preceding chapters. The first, a description of the forest industry in northern Ontario, presents a view of an industry with specific operational goals concerning the collection, presentation and reporting of information about forest depletions including clearcuts. The second reviews research into a specific application of LANDSAT imagery, namely the classification of clearcuts. The purpose of this applied research is to evaluate the information content of the imagery in various settings.

In this chapter, a technical analysis of LANDSAT imagery is applied to a small study site in northern Ontario. Specifically, clearcuts are interpreted and mapped from a LANDSAT Thematic Mapper image. The results are then compared to those obtained by conventional means. The choice of method, mapping technique and analysis of results are selected to give primary importance to the operational requirements of the foresters. In analyzing the technical results the following areas will be addressed:

- (1) the classification accuracy of the Thematic Mapper imagery
- (2) the minimum size of clearcut that is detectable and mappable
- (3) the positional accuracy of the Thematic Mapper imagery compared with supplementary photography

The meeting of other requirements of the foresters will be dealt with in Chapter 5.

4.2 Study Area

Pelletier Township is one of approximately 80 townships falling within the Hearst administrative district in northern Ontario (Figure 4-1). The township is typical of the forest mixture covering much of northern Ontario. Large softwood stands of Picea mariana (black spruce), are widely distributed across the township. These stands, when mature, are of prime importance for harvesting for use in the pulp and paper industry. Pinus banksiana (jack pine) has a more limited distribution within the black spruce stands but can form near pure stands. Alnus rugosa (speckled alder) dominates the margins of streams and rivers while poorly drained marshy areas are scattered throughout the township. Pelletier township has been extensively logged since 1975 and as of 1984 about one third of the township was clearcut.

Figure 4-1. Location of Pelletier Township Study Area

4.3 Approach to Interpretation

A visual interpretation technique using a single date LANDSAT Thematic Mapper image and a direct transfer of changes to a Forest Resources Inventory base map was selected for this study. Although this approach is similar to the conventional method of identifying and mapping clearcuts from supplementary aerial photography, it has several advantages. For example, conventional photo-interpretation practices make use of tone, texture, pattern and contextual information contained in the scene (Estes, 1983). These attributes combined with the spectral information of a LANDSAT image should enable accurate identification of dramatic vegetation changes such as clearcutting. In addition, as explained in the preceding chapter, a visual technique is the only one that enables features derived from the remotely sensed imagery to be directly transferred to a map. Since the foresters do not presently use digital forest inventory maps, yet have an operational need for change information to be integrated with forest inventory attributes, a direct transfer approach seems to be appropriate. A convenient byproduct of using this approach is that the map of clearcuts derived from Thematic Mapper imagery is more easily compared to the conventionally derived maps since both use the same base map.

Other advantages of a visual approach include the

lower cost of photographic image products and visual interpretation equipment compared with digital image analysis systems. Since relatively little money is currently invested by foresters in the acquisition and interpretation of supplementary photography combined with the negligible differences in classification and positional accuracy between digital and visual methods, this approach is more likely to be adopted by foresters, should it prove successful.

4.4 Remotely Sensed Imagery

The remote sensing data sets used for mapping and comparing clearcut boundaries were LANDSAT Thematic Mapper imagery, supplementary 35 mm aerial photography and 1:50,000 aerial photographs. The aerial photography and Thematic Mapper image were obtained in a diapositive format because the dynamic range of film products is significantly greater than that of print media, thereby enabling more of the spectral information to be retained (Ahern and Siróis, unpublished). Conveniently, diapositives are most effectively used with projection equipment for transferring information.

All the remotely sensed images were taken in 1984. However, as previously mentioned, the foresters using supplementary photography would acquire their data each year and add the changes to the previous year's map, thus

mapping changes cumulatively over the nine year period.

The image sources relevant to this study are listed in

Table 4-1.

<u>Imagery</u>	<u>Type</u>	<u>Scale</u>	<u>Date</u>
LANDSAT Thematic Mapper	natural colour (bands 1,2,3)	1:500,000	Aug 8, 1984
Supplementary Photography	black and white	1:15,840	Spring, 1975-84
Aerial Photography	black and white	1:50,000	Spring, 1984

Table 4-1 Imagery used for mapping clearcuts in Pelletier Township

4.5 Interpretation Methods

4.5.1 Thematic Mapper Image

The LANDSAT Thematic Mapper image was merged with an unmarked 1:15,840 Forest Resources Inventory map of Pelletier Township using a Procom-2 optical instrument. The Procom-2 is an optical transfer instrument designed to allow small scale data such as LANDSAT images to be superimposed on medium and large scale maps (Gregory et al., 1982).

The combining of the image and map not only facilitates data transfer but also enables an interpreter to use

both sets of data to guide the interpretation. For example a rock outcrop or marsh, in some instances, can appear similar to a clearcut on a Thematic Mapper image. The map information may resolve this confusion by containing information that will either verify or conflict with the initial interpretation. Hence, a more accurate classification may result.

The projected image was merged with the 1:15,840 Forest Resources Inventory base map. Features common to both data sets were used for common geographic referencing. These features include rivers and streams, marshes and roads. Using this technique, the boundaries of all the clearcuts found within the 205 km² area of Pelletier township were delineated on the Forest Resources Inventory map.

4.5.2 Supplementary Photography

A 1:15,840 map of forest clearcut harvesting was compiled using supplementary photography by forestry staff of the Ministry of Natural Resources at the Hearst district office. The harvested areas for each year between 1975 and 1984 were delineated on the map. The clearcuts were transferred to the map from print enlargements of the 35 mm negatives by means of a Sketchmaster optical transfer device. Since the Sketchmaster contains little correction capability, the transfer procedure must make use of common

features for local registration, in a similar way to the interpretation of the Thematic Mapper imagery. The method of updating FRI maps using supplementary photography is described in 2.5.2 and by Zsilinszky (1969 and 1972).

4.5.3 1:50,000 Aerial Photography

A comparison of cuts identified from Thematic Mapper imagery could simply be compared with the supplementary photography in order to obtain a measure of the area classified correctly. However, from such a comparison it could not be determined which method was more accurate than the other. Due to the absence of an accurately plotted map of clearcuts with stated reliability and accuracy that could be used for ground reference data, an interpretation of 1:50,000 black and white aerial photography was done. Such an interpretation allowed the classification and positional accuracies of both the supplementary photography interpretation and Thematic Mapper imagery to be measured.

Clearcuts were transferred to a clean copy of the 1:15,840 forest base map using a Kail enlarger-reducer apparatus. The local registration technique used for the Thematic Mapper and supplementary photography interpretations was also used for this interpretation.

A simple, yet effective, technique was employed to ensure accurate positioning of clearcuts relative to the Forest Resources Inventory map. Clearcuts were only mapped

within a central portion of each photographic frame. In choosing such a technique, it was assumed that the nadir point of the photograph, around which the least geometric distortion occurs, corresponds approximately to the centre of each photographic print. The interpretation of clearcuts from the central area of the photograph combined with the local registration technique enabled the inherent geometric distortions of the photography to be minimized. Although it is recognized that mapping with 1:50,000 photography is not error free, it is believed to be the most accurate in the classification and positioning of clearcuts of all the remotely sensed data sources used in this study. Therefore, it is suitable as a reference for comparison with the other interpretations.

4.6 Preparation of Maps for Analysis

In order to allow easier handling and digitizing of clearcuts, each of the maps corresponding to the three interpretations of remotely sensed data was photo-mechanically reduced to a scale of 1:20,000 using a high quality cartographic copy camera. The clearcuts depicted on the three maps were manually digitized using "Tydig", the digitizing software component of SPANS, a geographic information system that operates on a microcomputer. The analytical capability of the SPANS system facilitates the overlaying, measurement and spatial comparison of the three

maps.

Once within the GIS, each of the digitized co-ordinates of the clearcut polygons are converted to longitude and latitude co-ordinates based on two reference points placed in the system during the digitizing procedure. The longitude and latitude co-ordinates are then converted to a computer compatible co-ordinate system. These positions are in turn converted into individual map files of clearcuts suitable for display and analysis.

Each of the three 1:20,000 FRI maps was manually digitized and entered in the SPANS GIS. For data compaction purposes, SPANS employs variable pixel sizes called quadtree levels that enables large uniform areas within a polygon to be stored as large pixels while the more complicated edges of polygons are stored as smaller pixels. For the digital maps of Pelletier township, the smallest pixel size at a quadtree level of 11 corresponds to a size less than 0.5 mm x 0.5 mm on the original maps. For a manual mapping procedure, it is generally believed that the delineation of boundaries is no better than ± 0.5 mm. Therefore, the use of a quadtree level greater than 11 in the creation of a digital map is unnecessary.

4.7 Results

4.7.1 Results of Mapping

The computer maps generated from the SPANS GIS that

show clearcutting for the period 1975 to 1984 as identified from the Thematic Mapper, supplementary photography and 1:50,000 aerial photography are presented in Figures 4-2, 4-3 and 4-4.

4.8 Analysis of Mapping

A conventional analysis of results of the interpretation of remotely sensed imagery makes use of a confusion matrix in which the polygons of each class are spatially compared with ground reference data. For the mapping of clearcuts as done in this study, a typical confusion matrix does not work well for several reasons. Firstly, because clearcuts represent the only feature on the maps, the confusion with other mapped features cannot be determined. Secondly, the pattern of clearcutting in Pelletier Township is one of large contiguous areas. The verification of clearcuts on a polygon-by-polygon basis becomes unrealistic since the map is composed of several large polygons and a small number of very small and moderate sized polygons. Thus, in order to compare various differences between the three maps, several types of alternative spatial comparison of clearcut areas were undertaken.

4.8.1 Simple Areal Analysis

4.8.1.1 Total Area Comparison

A visual comparison of the computer generated maps of

Figure 4-2. Clearcuts of Pelletier Township, 1975-1984,
from Thematic Mapper

Figure 4-3. Clearcuts of Pelletier Township, 1975-1984,
from supplementary photography

Figure 4-4. Clearcuts of Pelletier Township, 1975-1984,
from 1:50 000 aerial photography

clearcuts identified from the Thematic Mapper image, supplementary photography and 1:50,000 photography (Figures 4-2, 4-3 and 4-4), show that, in general, the overall shape and distribution of clearcuts on all three maps is quite similar. This similarity is extended to the total measured area of the clearcuts. An area analysis of the maps (Table 4-2) reveals that 6525 ha of clearcuts were identified from the Thematic Mapper compared with 6732 ha for supplementary photography and 7149 ha for the 1:50,000 photography. There is less than 9% difference in the total area between Thematic Mapper and the 1:50,000 photography.

	<u>TM</u>	<u>SAP</u>	<u>AP</u>
Total Area Clearcut (ha)	6525	6732	7149
TM & SAP as % of AP	91.3	94.5	
TM as % of SAP	96.9		

Table 4-2. Total area of clearcuts identified from Thematic Mapper (TM), supplementary aerial photography (SAP) and 1:50,000 aerial photography (AP).

4.8.1.2 Two Map Overlay

In order to compare differences between clearcuts identified from Thematic Mapper and supplementary photography, a digital overlay was created using SPANS.

The overlay is shown in Figure 4-5. The map shows that although the area of clearcuts mapped from Thematic Mapper map is 6525 ha, 5807 ha or 89% of these cuts occupy the same geographic space as the supplementary photography interpretation (Table 4-3). In other words there are 719 ha of clearcuts that were mapped from the Thematic Mapper but not found on the supplementary photography interpretation.

	Thematic Mapper		Supplementary Photography	
	ha	%	ha	%
TOTAL CUT	6525		6732	
COMMON AREA	5807	(89.0)	5807	(86.3)
UNIQUE AREAS	719	(11.0)	926	(13.7)
UNIQUE AREAS VERIFIED by AP	573	(79.7)	549	(59.4)
MODIFIED AREA	6380		6356	

Table 4-3. Comparison of Thematic Mapper and supplementary photography interpretations of clearcuts and differences verified by 1:50,000 aerial photography (AP).

Of the 719 ha of clearcuts unique to the Thematic Mapper interpretation, 573 ha were verified as being cuts

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Figure 4-5. Overlay of clearcuts identified from Thematic Mapper and supplementary photography

from the 1:50,000 aerial photography, which leaves the remaining 146 ha not found on any data set. Similarly, of the 6732 ha mapped from supplementary photography, 926 ha do not occupy the same location as the clearcuts identified from the Thematic Mapper. Of this 926 ha, 549 ha were verified from the 1:50,000 aerial photography.

This simple comparison shows that although the total area of clearcuts identified using the supplementary photography was greater than that found using the Thematic Mapper, a larger proportion of the cut area was not confirmed by the reference photography. However, when the common area is added to the unique areas verified by the 1:50,000 photography, the resultant modified area of clearcuts is slightly greater for cuts identified from Thematic Mapper than those from supplementary photography (6380 ha versus 6356 ha respectively). This comparison seems to indicate that the Thematic Mapper and the supplementary photography are more or less equal in identification of clearcuts.

4.8.1.3 Three Map Overlay

While a two map comparison reveals the differences between the Thematic Mapper imagery and supplementary photography and some potential sources of errors in the uniquely classified areas, it does not indicate the possible common sources of error. Without addressing such

an omission, it appears that because clearcut areas share a common location on both maps, there is a clearcut at that location. A comparison of all three sets of data can be made to increase the confidence in the actual classification of clearcuts.

Using the multiple overlay capability of SPANS, two overlays were made of the clearcut area identified from the Thematic Mapper imagery and the supplementary photography and compared with the 1:50,000 aerial photography (Figures 4-6 and 4-7). The area analysis (Table 4-4) shows that 5648 ha of clearcuts were mapped in the same geographic space on all three sets of imagery. There were 146 ha mapped from the Thematic Mapper that were found on no other data set while 377 ha mapped from supplementary photography were not found on any other data set.

This three map comparison suggests that there are likely fewer errors of commission from mapping with Thematic Mapper compared with supplementary photography since only 146 ha or 2.2% of the cuts mapped from Thematic Mapper were found on neither the supplementary photography nor the 1:50,000 aerial photographic interpretation. By comparison, 377 ha or 5.6% of the cuts mapped from supplementary photography were not found from mapping with either the Thematic Mapper or the aerial photography.

Figure 4-6. Overlay of clearcuts identified from Thematic Mapper and 1:50 000 aerial photography

Figure 4-7. Overlay of clearcuts identified from supplementary photography and 1:50 000 aerial photography

INTERPRETED RESULTS

		<u>TM</u>		<u>SAP</u>		<u>AP</u>	
		(ha)	(%)	(ha)	(%)	(ha)	(%)
C	ALONE	146	(2.2)	377	(5.6)	379	(5.3)
O							
M	TM + SAP	158	(2.4)	158	(2.3)		
M							
O	TM + AP	573	(8.8)			573	(8.0)
N							
A	SAP + AP			549	(8.2)	549	(7.7)
L							
I	TM + SAP + AP	5648	(86.6)	5648	(83.9)	5648	(79.0)
T							
Y							
TOTAL		6525	(100)	6732	(100)	7149	(100)

Table 4-4. Comparison of commonality of Thematic Mapper (TM), supplementary aerial photography (SAP) and 1:50,000 aerial photography (AP) interpretations of clearcuts.

The spatial differences between the Thematic Mapper, supplementary photography and 1:50,000 photography can be viewed as being due to two types of errors. Some of these differences may be described as classification or interpretation errors, which result from errors of omission or commission in the interpretation process. Other errors may be considered positional errors. These errors occur when the same clearcut is contained on two maps but the location or position of the clearcuts on the two maps is substantially different. The isolation of each type of error, and the measurement of the magnitude and relative contribution of each to the total accuracy of clearcut mapping now

becomes a key part of the more detailed analysis.

4.8.2 Classification Error Analysis

Classification errors are those errors of omission or commission that occur during the interpretation process. They are found on any of the three remotely sensed interpretations. These errors, especially when a visual mapping procedure is applied, can arise from human error during interpretation or digitization or from the remotely sensed data itself which, for a variety of reasons, may not reveal the full extent of the features being mapped. A secondary source of classification error can result from the optics of the interpretation equipment. This latter source is considered minor because of the use of the Forest Resources Inventory maps for positional control.

The 1:50,000 aerial photography was used as a reference interpretation against which the classification of clearcuts identified from the Thematic Mapper imagery and supplementary photography was measured.

4.8.2.1 Comparison of Selective Areas

Since classification and positional errors are often difficult to separate, a number of large obvious classification errors were selected from the Thematic Mapper and supplementary photography maps of clearcuts.

The main criterion for selecting polygons with only

classification errors was to find clearcut polygons on either map that were unique to one interpretation. The lack of any similarly shaped feature on the other map indicates that positional displacement can be ruled out. Figure 4-8 illustrates how polygons of classification errors were selected.

A detailed comparison was made of the Thematic Mapper and the supplementary photography maps. Ten areas representing the largest differences between the two interpretations were selected (Figure 4-9). Five of these cuts, ranging in size from 9 to 42 ha, were the largest clearcuts identified on the Thematic Mapper but omitted on the supplementary photography interpretation. The other five polygons represent clearcuts found on the map derived from supplementary photography map but not mapped using the Thematic Mapper imagery. The individual cuts ranged in size from 16 to 29 ha. The total size of the test sample was 200 ha or about 12% of the 1645 ha of the unique areas of the Thematic Mapper and supplementary photography interpretations.

The ten areas were compared to the map of clearcuts derived from the 1:50,000 aerial photography in order to confirm which of the interpretations was more correct. The results are presented in Table 4-5. For the five areas totalling 90 ha that were uniquely classified as cuts from Thematic Mapper, 67 ha or 74% were verified as clearcuts

A. CLASSIFICATION ERROR

B. POSITIONAL ERROR

Figure 4-8. Visual distinction between classification and positional errors

Figure 4-9. Ten polygons representing large areal
classification differences between Thematic
Mapper and supplementary photography

from the aerial photography. Similarly, for the five areas totalling 110 ha that were uniquely classified as clearcuts from the supplementary photography interpretation, 70 ha or 64% of the cuts were verified by the 1:50,000 aerial photography.

The results indicate that for these known classification differences between supplementary photography and Thematic Mapper that could be definitely identified as omissions in mapping, the Thematic Mapper performed no worse and perhaps slightly better, than the supplementary photography.

<u>CUT #</u>	<u>UNIQUE TM</u> (ha)	<u>UNIQUE SAP</u> (ha)	<u>VERIFIED BY A/P</u> (ha) (%)	
1	42		29	69
2	13		9	69
3	10		3	30
4	9		7	78
5	16		14	88
6		16	9	56
7		29	21	72
8		27	15	56
9		20	15	75
10		18	10	56
		<u>110</u>		63.6
	<u>90</u>			73.8

Table 4-5 Comparison of large area classification differences between Thematic Mapper and supplementary photography.

4.8.2.2 Minimum Mapping Size

The minimum size of mapping unit refers to the smallest size of feature that will be mapped at a given scale of map. For example, in topographical mapping, area features such as lakes will only be mapped if they meet certain size criteria for a particular mapping scale. On thematic resource maps the minimum size is often given as 1 cm² for area features. This size corresponds to about 1 ha on a 1:15,840 Forest Resources Inventory map.

All types of remotely sensed imagery have a minimum size under which features can either no longer be detected or accurately mapped. In the case of LANDSAT imagery, the poor ground resolution can often make the discrimination of areal features more difficult than would be expected with most types of aerial photography. Therefore, in a forest environment where there are many small clearcuts, imagery with a certain ground resolution may be unsuitable for detection and mapping of a certain critical size of clearcut.

In order to quantitatively measure the minimum size of clearcut detectable, many sizes of clearcuts mapped from Thematic Mapper imagery should be compared with reliable ground information. However, for the Pelletier township study, most of the clearcuts are large, contiguous areas and therefore a large sample of smaller cuts was not obtainable.

However, a qualitative indication of the minimum size of clearcut that can be detected by using Thematic Mapper data can be made. Two areas were selected for comparison between Thematic Mapper and supplementary photography. Both areas contained regularly-shaped squarish clearcuts in a checkerboard pattern. The first site, located in the north-central part of Pelletier township, contained cuts that were each about 2 to 4 ha. The other site, found in the east-central part of the study, was dominated by cuts of about 1 to 2 ha each. These two sites are shown along with their depiction on the Thematic Mapper, supplementary photography and 1:50,000 photography maps in Figures 4-10 and 4-11.

The site depicting moderately small clearcuts (Figure 4-10) shows that cuts of this size range are quite similar in terms of shape. Although the pattern of cutting has remained intact, the cuts on the Thematic Mapper interpretation appear to be more sparsely distributed than those identified from the supplementary or 1:50,000 aerial photography. A visual comparison of these two sites indicates that clearcuts have been detected on all maps. The site of smaller clearcuts (Figure 4-11) shows that clearcuts identified from the supplementary photography tend to have a similar pattern to those identified from the 1:50,000 photography. However, individual cuts are generally smaller in size on the supplementary photography.

Figure 4-10. Comparison of moderately small (2-4 ha) clearcuts

Figure 4-11. Comparison of small (1-2 ha) clearcuts

However, clearcuts interpreted from the Thematic Mapper image for this site tend to distort and merge together. Clearcuts can be detected in this site but they are too small in area to be delineated as accurately as cuts from the other two data sets.

This qualitative analysis seems to indicate that Thematic Mapper imagery can be used to detect very small areas of clearcuts. However, the correct portrayal of the shape of clearcuts is difficult and the measurement of area may fluctuate widely compared with the actual area. These small cuts represent only a small percentage of the total clearcut operations in Pelletier Township.

4.8.3 Positional Error Analysis

Positional errors in a mapping process are those in which the boundary of a mapped feature is displaced from its true position in geographic space. This type of error is more fully described in section 3.4. Positional errors may arise from inaccuracies in the geometry of the remotely sensed imagery, distortions of the mapping or transfer equipment, human error in the mapping process, or combinations of the above. As well, the base upon which the changes are mapped can have geometric errors which may not be uniform across the map. Finally in the manual digitizing process, the mapped boundaries may not always be accurately followed by the cursor, thereby resulting in

errors that cause positional errors in the digital map files.

While all of the types of positional error may be difficult to isolate and quantify, some have been minimized by the mapping technique used. Determining the position of clearcut polygons in relation to a set of well distributed control features on the Forest Resources Inventory base map enables the geometric errors contained in the data set and transfer equipment to be minimized. The fact that the same base map was used for each interpretation minimizes the geometric error associated with using different base maps. Errors due to digitizing of clearcuts can be eliminated in the measurement of selected points of positional errors, because the original maps were used. The only major source of error remaining is that of human error during the interpretation procedure and those errors associated with the quality of the imagery itself.

4.8.3.1 Comparison of Selected Areas

A general indication of the severity of positional error can be obtained by visually inspecting large anomalous areas found from the overlay of clearcuts derived from Thematic Mapper - supplementary photography overlay (Figure 4-5). Large discrepancies were chosen according to selected criteria. First, similarly shaped clearcut polygons or boundaries found on the overlay but displaced

2 of/de 2

MicroD

in position were sought. Since the shapes of small polygons are difficult to discern, only the largest errors can be positively identified using this procedure. A second criterion was that the selected areas had to be clearly recognizable as the same area on all three maps. In this way the confusion between positional and classification errors was minimized and the positional differences isolated. An illustration of how a displaced clearcut polygon boundary was differentiated from a classification error is illustrated in Figure 4-8.

Ten large displacement areas were selected (Figure 4-12). They totalled 145 ha or a 9% sample of the total area of difference between the Thematic Mapper and supplementary photography. Six of the clearcuts represented cuts which were identified only on the Thematic Mapper image. Of these six cuts, totalling 93 ha, 76 ha were confirmed from the reference photography as being correctly positioned. The other 4 cuts were solely interpreted on supplementary photography. Of these cuts, totalling 52 ha, 32 ha were determined to have been positioned correctly. Because a slightly higher proportion of the cuts mapped with Thematic Mapper imagery were confirmed with the 1:50,000 aerial photography, the Thematic Mapper imagery may be slightly better in positioning than supplementary photography. While these figures do not indicate the proportion of positional error compared with classification,

Figure 4-12. Ten polygons representing large positional differences between Thematic Mapper and supplementary photography.

error, they do serve to show that positional displacement is an important component of the total error. The results of the comparison of the displaced areas are shown in Table 4-6.

<u>CUT #</u>	<u>UNIQUE TM</u> (ha)	<u>UNIQUE SAP</u> (ha)	<u>VERIFIED A/P</u> (ha)	<u>%</u>
1	40			
2	12			
3	12			
4	8			
5	12			
6	9			
7		17		
8		10		
9		9		
10		15		
	93.....	52.....	76	82%
			32	62%

Table 4-6 Comparison of large areal positional differences between Thematic Mapper and supplementary photography.

4.8.3.2 Point Comparisons

Using the original maps of clearcuts, common points on both the Thematic Mapper and supplementary photography maps were selected for positional comparison. The vectors of displacement were drawn from each point to the reference point as determined from the 1:50,000 photography. An illustration of how points of displacement were selected is

shown in Figure 4-13.

The points used for positional comparison were selected on the basis of three criteria. First, the points were selected at prominent locations and represented the most obvious differences that could be found between the two interpretations and the reference map. Secondly, the points were clearly visible on all three maps so that identical points were being compared. Finally, the points were well distributed across the mapped area in order to discern patterns in the displacement of clearcuts.

A total of 70 such displacement points taken from clearcuts distributed across the map area were chosen (Figure 4-14). Thirty-five of these points were the largest positional differences found between the supplementary photography and the control photography. The corresponding points on the Thematic Mapper map were then identified. A measurement of the distance between the control position and the point as located on each of the other maps was calculated.

Another 35 large, well distributed displacement points were then selected from a comparison between the 1:50,000 aerial photography and the Thematic Mapper map. The corresponding points on the supplementary photography were then plotted. Displacement distances between each of the two interpretations and the reference position were then calculated.

Using the original maps, positional displacements of clearcut boundaries are calculated by selecting prominent points visible on the maps derived from each set of remotely sensed imagery. The distances between Thematic Mapper and the 1:50 000 photography (e.g., $a - a'$) and supplementary photography and the 1:50 000 photography (e.g., $a - a''$) are then measured to the nearest 0.5 mm (10 m on the ground).⁶

Figure 4-13. Measurement of displaced points

Figure 4-14. Distribution of 70 points representing large positional differences between Thematic Mapper and supplementary photography

For the total 70 displaced points, the Thematic Mapper interpretation averaged 67 m while the mean displacement for the supplementary photography was 86 m. Using standard deviation statistical analysis, the positional differences between Thematic Mapper and the 1:50,000 aerial photography was ± 70 m at the 95% confidence level. By way of comparison, the positional differences between supplementary photography and the aerial photography was ± 122 m at the same confidence level.

For the 35 largest displaced points found from the supplementary photography, the average displacement was 117 m. When these same points were mapped with Thematic Mapper, the displacement was 54 m. In other words, the displaced points of supplementary photography averaged twice as far as the corresponding Thematic Mapper position when compared with the control photography. The 35 largest displaced points from the Thematic Mapper imagery averaged 82 m while the supplementary photography averaged 62 m or only 20 m better for the same points.

This displacement of specific points suggests that Thematic Mapper imagery, when used as in this study, can accurately position clearcuts within a narrower range of displacement error than supplementary photography. The largest expected positional errors would be about ± 82 m or about 2.5 pixels compared with about ± 114 m for the largest positional errors from supplementary photography.

While this does not approach the ± 0.5 pixel accuracy calculated as obtainable using LANDSAT from other research (e.g., Archibald and Ahern, 1985), it should be noted that only the largest discrepancies were measured. Most of the clearcuts were positioned quite accurately as can be seen by visually inspecting the perimeter of clearcuts in Figures 4-6 and 4-7.

The poorer performance of supplementary photography in positioning may be explained partly from the distortions in the data itself. The photography is acquired at relatively low altitudes and is subject to greater geometric distortion than the Thematic Mapper, which is more geometrically correct because of the altitude of the satellite and the standard geometric corrections applied to the data. As well, each supplementary photographic frame has a small field of view of about 13 km^2 . In areas where the control needed for image registration to the map is beyond one frame, the accurate positioning of clearcuts becomes more tenuous. The relatively large field of view of the Thematic Mapper imagery is the area of the entire FRI map base (i.e., 81 km^2). This field of view enables geographic control to be established over a large area. This is substantiated by observing that the clearcuts found in close proximity to good control features such as lakes and marshes tended to be mapped in a similar position using any of the three data sets. However, the largest displace-

ments were in areas farther from water bodies and often close to the edge of the map where control features are more difficult to find. For example, the clearcuts located along the east edge of the map were positioned with a greater degree of accuracy using LANDSAT than with supplementary photography as may be seen by visually comparing Figures 4-6 and 4-7.

It should be emphasized that these measured positional errors are the extreme cases and represent only a small proportion of the total perimeter of all the clearcuts. The average displacement error could be determined from a large sample of points systematically chosen regardless of the magnitude of the displacement. This will be difficult, however, because minor differences in shape will be a mixture of classification and positional errors.

4.9 Discussion

A visual mapping technique, similar to that presently used by foresters, was adapted to enable the mapping of clearcuts from LANDSAT Thematic Mapper imagery. The technique consists of three key features: the enlargement of the imagery to a scale of 1:15,840, the combining of FRI map information as an integral part of the interpretation process and thirdly, the direct mapping of clearcuts on the 1:15,840 FRI map.

The technique appears to have success in achieving

results that are comparable to the conventional method of using supplementary photography for several measured and observed technical parameters. Although the total area of clearcuts mapped was less using Thematic Mapper, than with supplementary photography, the area of cutting verified by the 1:50,000 photography was about the same, indicating that similar interpretation accuracy is obtainable using Thematic Mapper. Based on selecting a sample of obvious classification errors Thematic Mapper performed almost equally well compared with the supplementary photography. However, the Thematic Mapper imagery has a spatial resolution of 30 m that limits the ability to delineate the shape of small clearcut polygons as accurately as supplementary photography.

This classification accuracy of Thematic Mapper was found to be comparable to other studies of clearcut mapping using MSS data. The combined accuracy for this study is no less than 86% if only the overlap area with the 1:50,000 aerial photography is considered. Accuracy was measured as high as 97% when compared only with supplementary photography. This range of accuracy using Thematic Mapper compares favorably with previous studies using MSS but does not represent a significant improvement. This result is reasonable considering that the Thematic Mapper colour image did not have an infrared band which is highly sensitive to dramatic changes in vegetation cover. A

further improvement in accuracy would be expected had Thematic Mapper band 4 been included. The use of an infrared band would most likely improve the detection of clearcuts; particularly for the older cut areas where significant regrowth has occurred. The value of an infrared Thematic Mapper band 4 for forestry purposes has been well documented (Benson and Degloria, 1985; Horler and Ahern, 1986).

The age of the clearcutting may also be a factor in the accurate delineation and classification of clearcuts. Both the LANDSAT Thematic Mapper and the 1:50,000 aerial photography were acquired in 1984. Hence the detection of clearcutting that had taken place in mid 1970's was more difficult than the newer clearcuts. This is due to regrowth in the cutover area over the nine year time frame. As was found by others, misclassification of LANDSAT imagery can result when new vegetation has a chance to establish itself (e.g., Dixon et al., 1982). Since the supplementary photography is acquired cumulatively on a yearly basis, the recent cuts are readily visible.

In terms of positioning of these cuts relative to an Forest Resources Inventory map, the Thematic Mapper imagery is significantly better than supplementary photography for the largest most obvious positional errors. Because of the improved spatial resolution of Thematic Mapper over MSS, an improved positioning capability might be expected.

Based on these findings, the technical capabilities of Thematic Mapper imagery in terms of classification, positioning and ability to integrate results with Forest Resources Inventory maps appears to meet the requirements of foresters as determined from the industry profile described in chapter 2. However, the completeness of mapping using the natural colour Thematic Mapper (bands 1, 2 and 3) appears limited to sizes greater than 2 ha. Under this limit, the clearcuts can be detected but the mapping of the correct shape becomes more difficult. Consequently, measurements of these small areas will vary from the true situation. In the case of Pelletier Township, there are few of these areas.

4.10 Conclusion

With the technical capabilities of LANDSAT Thematic Mapper comparing favorably with supplementary photography, the extent to which the other requirements of foresters have been met should now be evaluated.

CHAPTER 5

SUMMARY, DISCUSSION AND CONCLUSION

5.1 Introduction

In chapter 4, it was found that Thematic Mapper imagery can be used to identify and map clearcuts with similar accuracy to supplementary photography. In this chapter these technical results in addition to other requirements of foresters will be explored. Such an examination will give a more complete picture of the ability of LANDSAT Thematic Mapper imagery to compete with conventional supplementary photography for the mapping of clearcuts.

5.2 Meeting The Forester's Requirements

The main requirements of the company and district foresters operating in northern Ontario and the ability of Thematic Mapper imagery to meet those requirements can be summarized as follows:

(1) Integration with Forest Resources Inventory Maps.

The clearcut information as derived from a remotely sensed data set should be capable of being integrated with the Forest Resources Inventory maps. The technique of using Thematic Mapper imagery as employed in this study was

satisfactory in this respect. One previous study that used MSS employed a direct mapping technique at large scales (Archibald and Ahern, 1985) while others have used intermediate scales (Windquest and Jackson, 1975, Murtha and Watson, 1975). Another study offered the flexibility of printout at any desired scale (Jano and Pala, 1983). Presumably the results could be manually transferred to the Forest Resources Inventory base map. However, in the present work it has been demonstrated that the integration of imagery and map can be used to aid the mapping process and produce accurate results comparable with the conventional technique.

(2) The information should be as complete and accurate as supplementary photography

From the analyses conducted in chapter 4, the Thematic Mapper interpretation was comparable to supplementary photography in total area of clearcut mapped. Clearcuts smaller than about 2 ha were generally detected from the Thematic Mapper imagery but their shape and area measurement were not as accurate as the supplementary photography. The Thematic Mapper imagery was significantly better in terms of the more prominent positional errors, particularly where geographic control was not found in the immediate area. Accurate placement of clearcut polygons helps ensure that change information derived from the map,

such as mix of species harvested, is accurate as well.

(3) Timely Acquisition of the Remotely Sensed Data.

An advantage of supplementary photography is that it can be acquired on relatively short notice since the photographic equipment, the camera mounting apparatus and access to aircraft are located near most of Ontario Ministry of Natural Resources district offices in northern Ontario (Zsilinszky et al., 1979). The availability of equipment to companies is not known, but presumably the acquisition of supplementary photography may be contracted out on relatively short notice. In theory, the supplementary photography imagery should reflect the state of the forest as of March 31, since that is the date specified by the Crown Timber Act. In practice, according to the responses to the questionnaire, the acquisition of supplementary photography takes place any time from March to August with a peak in May.

In comparison, Thematic Mapper imagery is continually acquired on a 16 day repeat cycle and offers the potential of 11 passes during the April to August time period. Generally, it could be expected that one or two relatively cloud-free images will be recorded during this period. The chances of acquiring a good quality scene during a more restricted time frame in March or April is uncertain due to the unpredictable presence of cloud cover. The use of

midwinter imagery is a possibility, although unproven for mapping clearcuts in a boreal forest environment. However, mapping of the conversion of wooded land to agriculture in Alberta has been shown to be accurate using winter LANDSAT imagery (Moore et al., 1982). The use of such imagery for mapping clearcuts could help ensure coverage close to the March 31 optimal date.

The availability of imagery after its initial acquisition is relatively fast for supplementary photography as photographic laboratories are normally nearby. With LANDSAT Thematic Mapper imagery, it would normally take a few weeks after a scene has been recorded to determine if a cloud-free, good quality image had been acquired and another 4-6 weeks to receive an image. Assuming that the reporting of clearcuts by the district offices is not required by the head office until September 31st, such a delay in obtaining data may not be too severe. However, foresters may need data earlier in the summer for other purposes.

An additional factor related to acquisition of imagery is the security of long term supply. The LANDSAT program has an uncertain future and there is no guarantee that the same imagery can be obtained into the next century. However, the data from other satellite platforms with similar sensors could be used in its place.

(4). Other Uses of the Remotely Sensed Data.

According to the results of the questionnaire, the supplementary photography that is used for mapping clearcuts is also used for several other purposes including mapping access roads, planning for future cutting, site preparation planning, fire damage, monitoring regeneration and mapping partial cutting. LANDSAT Thematic Mapper imagery has been shown capable of contributing to some of these needs such as mapping fire damage and roads (Ahern and Archibald, 1986). The accuracy of mapping these features would be expected to rival that of clearcuts since these also involve the dramatic removal of the vegetative cover.

The identification of more subtle spectral reflectance changes in the forest such as regeneration of forest cover may prove more difficult for LANDSAT imagery than supplementary photography. Multispectral scanner imagery has been used for regional scale monitoring of such changes with limited results. It is doubtful that Thematic Mapper imagery could replace conventional forms of remotely sensed data in detailed regeneration monitoring, site preparation and the monitoring of partial cutting. Each of these requirements of foresters requires further research of Thematic Mapper imagery to determine the extent that these requirements could be accommodated.

Given the message of the industry and Ontario Ministry

of Natural Resources foresters who favour Thematic Mapper imagery as a supplement to conventional methods, rather than a direct replacement (section 2.6.2) it is possible that the Thematic Mapper imagery could be used selectively in areas where other activities such as regeneration and site preparation are not occurring. Furthermore, this data may have some unique capabilities that would make it useful for other monitoring functions. For example, an entire management area can be covered, normally with one or two images. Such coverage may be useful for determining unforeseen changes such as forest damage due to flooding or tornadoes that may take place outside the recently harvested areas.

(5). Education and Training.

One of the more significant facts to come out of the survey of foresters in northern Ontario is the lack of knowledge of LANDSAT and its application to forest management problems. Remote sensing training has been generally regarded as high technology and a complete departure from the experience of many operational level foresters. However, the method of mapping clearcuts as described in this study would be a natural extension of the existing photo-interpretation skills of foresters. Such a method of using satellite data would likely be relatively easy to implement at the district office and industry.

Such use of 'intermediate' technology in another forestry application, fire prevention, was found to be the easiest and most successful for use by operational foresters (Kourtz, 1979). In that application image enhancements, rather than image analysis, were used for fire prevention planning.

A requirement for training of foresters in basic remote sensing skills has been noted by foresters who have seen the potential of LANDSAT imagery (e.g., Flowers, 1979, Millar, 1979). Flowers suggests that field managers and supervisors must be kept up to date on developments in remote sensing stressing its potential value as a management. He also mentions the difficulty of convincing upper management of the importance of developing interpretive skills in remote sensing for the working level forester. It is clear that Flowers sees the use of remote sensing by those foresters who presently collect and assimilate other information in support of forest management. Such a requirement is as true today as it was when these remarks were made.

(7). Costs.

The acquisition costs for supplementary photography were found to average about \$5000.00 per year for each Ontario Ministry of Natural Resources district or company management area. This compares with a data cost of

\$335.00 (1988 price) for one LANDSAT Thematic Mapper three band colour composite scene that would cover over 100 townships the size of Pelletier township. The costs of manpower required to conduct the interpretation would likely not differ from that required for current visual techniques of interpretation applied to supplementary photography. Slightly more time may be involved during the supplementary photography interpretation since more frames would be handled and a certain amount of time and expense invested in the training of foresters in satellite imagery and visual interpretation techniques would be necessary. However, this expense should be less than training in computer image analysis since the principles of visual interpretation are similar to photo-interpretation techniques. Specialized equipment that is not now available would be required, however. An image transfer device such as used in this study currently costs about \$17,000.00. However, a standard 35 mm projector can be used effectively for the same purpose. The LANDSAT images must be cut up and mounted in slides. About four townships the size of Pelletier would be contained on each slide.

5.3 Discussion

In an attempt to compare objectively many of the technical and non technical factors associated with the utility of Thematic Mapper imagery versus that of

supplementary photography, a utility analysis was performed based on a system developed by Stern et al., (1976) (APPENDIX B). The results showed that for the seven categories compared, Thematic Mapper imagery was 88% as effective as supplementary photography for meeting the requirements specified as important by foresters. Thematic Mapper imagery scored better in some categories such as positional accuracy. For others categories such as flexibility of data for other uses and image availability, supplementary photography scored higher.

While LANDSAT cannot meet all the requirements of foresters in all areas where supplementary photography is now used, the technical results achieved in this study are similar to supplementary photography in terms of the factors expressed as important by the foresters presently conducting clearcut monitoring and mapping. It would appear that non technical factors such as insufficient knowledge and training in remote sensing interpretation may be more serious impediments to the utilization of Thematic Mapper imagery. These factors have been studied for numerous types of new techniques which have the potential to replace existing methods or products. Among these factors, learning has been isolated as one which determines the scope for utilization of a technique (Sahal, 1981). Learning of the capabilities of Thematic Mapper imagery could take place through demonstration and training

sessions in image interpretation. Training sessions should not only demonstrate the content of the imagery but also show how the required products such as overlays suitable for combining with forest inventory maps can be obtained.

Sahal (1981) also states that once a new technique has become established it often will undergo further development and evolution both by the producers of the technique and through continued utilization of the technique, thereby creating change and adaptation. In the context of this study, the producers of the technique would be the remote sensing research community and the users would be the foresters themselves. Once the use of Thematic Mapper imagery has been accepted by foresters for a particular requirement such as clearcut mapping, they may adapt the imagery for other monitoring functions.

It is interesting that the common approach taken towards utilizing remote sensing for developing countries is similar to the approach taken in this study. For example, Simonett (1977) provides four basic guidelines for using remote sensing for resource management purposes. These are outlined below:

- (1). Demonstrate that the data collected can be assimilated and integrated into current or near-term operations.

- (2). Search for the most cost effective means for data collection.
- (3). Plan remote sensing data acquisition in light of both management as well as conventional applications.
- (4). Develop a data management system capable of efficient storage, retrieval and manipulation of data.

These guidelines seem appropriate for the needs of all resource managers, including foresters, in developed countries as well as underdeveloped nations.

5.4 Recommendations for Further Research

The research contained in this thesis has inspired several areas of possible follow-up work that may help to establish more firmly the thrust of user-oriented, "appropriate" research.

- (1). A more effective and rigorous methodology that could help separate classification errors from positional errors is needed. Often in resource application, the knowledge of "where" an activity or feature is occurring is just as important as "how much" activity. The marriage of applications studies with cartographic and GIS technology by the remote sensing

research community might prove useful to achieving this goal.

- (2). A more complete study of the minimum size of mappable feature from satellite data in a mapping context is needed. The knowledge of critical sizes of point, line and area features for detection, mapping and measurement purposes would aid resource managers such as foresters to determine if the data can meet their information needs at a specified level of detail.
- (3). The usefulness of the Thematic Mapper infrared bands for forestry purposes has been well documented (Benson and DeGloria, 1985, Ahern and Horler, 1985). While this study used a natural colour Thematic Mapper product, the inclusion of an infrared band (band 4 especially) would most certainly have improved the results. Therefore a more definitive study of the completeness and cartographic accuracy of mapping clearcuts using Thematic Mapper infrared spectral bands would be useful.
- (4). The development of a model that integrates satellite remote sensing capabilities and the requirements of potential users could be useful. Factors itemized by Sahal (1981) such as learning, utility and diffusion

over time and space, in addition to technical competence could be explored and perhaps quantified. Such a model might aid the development of more effective and flexible uses of remote sensing technology in many fields, including forestry, and make "applications research" truly applied for those groups who would gain the most by using such information.

5.5 Conclusion

The results of this research indicate that LANDSAT Thematic Mapper imagery possesses information content about clearcuts which rivals that of the conventional data source of supplementary aerial photography. The ability to detect, map and measure clearcuts accurately, except for very small cuts, equals or exceeds the conventional means using supplementary photography. These results indicate that Thematic Mapper imagery can supply much of the information for forest clearcutting in a satisfactorily complete, accurate and cost effective manner that could be used by operational level foresters in northern Ontario, without a significant amount of additional training.

By considering the foresters as an integral part of this research design, the practical approach to mapping clearcuts developed in the preceding pages has good potential to be of benefit to this resource sector.

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APPENDIX A

SURVEY OF NORTHERN ONTARIO FORESTERS
REGARDING CLEARCUT MAPPING

January 24, 1986

District/Company Forester
District MNR
Small Town
Ontario

Dear Sir:

Enclosed you will find a short questionnaire designed to determine the present methods of acquiring, interpreting mapping and reporting of information pertaining to clearcut harvesting in northern Ontario.

The results will be used as part of a masters thesis in geography and will guide the development of a methodology of using LANDSAT satellite images in such a way that it is responsive to technical, economic and administrative constraints of foresters operating in northern Ontario.

It would be most appreciated if you would spend ten minutes to contribute the experience of your organization to this project.

If you are interested in the results of this research and would like to be informed of the findings, please indicate as such on the questionnaire.

Thank you for your valuable contribution to my MA research.

Yours truly,
A.M. Turner
Department of Geography
Carleton University
Ottawa, Ontario
K1S 5B5

Forest Clearcut Questionnaire*

*IMPORTANT: For the purposes of this questionnaire, clearcutting will refer to the harvesting of all merchantable timber from an area of forested land.

Please feel free to enlarge upon any of your answers in order to make the meaning more precise.

Name:

Title:

Company/Agency:

Address:

Questions pertain only to the situation in the area of jurisdiction of your company or district.

1. Is the information about forest clearcutting acquired by your company/agency?
 - a. yes
 - b. no
2. What is your present source of information regarding forest clearcuts? (Check one or more)
 - a. aerial photography
 - b. field mapping
 - c. airborne mapping (personal observation)
 - d. LANDSAT tapes
 - e. LANDSAT images
 - f. information obtained through another company or agency.
3. At what scale are forest clearcuts mapped?
 - a. 1:15,840
 - b. other (specify)
4. Is forest clearcut information normally integrated with FRI (forest stand) maps?
 - a. yes
 - b. no

5. If yes to 4, is the information presented as:
- a. overlay?
 - b. mapped directly on paper map?
 - c. other (specify)
6. If no to question 4, briefly explain how clearcut information is mapped or compiled?
7. Circle the month in which forest depletion information is normally acquired.
- J F M A M J J A S O N D
8. How often is such information acquired for your area?
- a. more than once a year
 - b. yearly
 - c. biennially
 - d. other (specify)
9. If you presently use aerial photography, what other information is obtained in addition to forest clearcuts?
- a. partial (selective) cutting?
 - b. regeneration monitoring?
 - c. access roads?
 - d. extent of fire damage?
 - e. other depletions due to features such as powerline corridors, pipelines farmland expansion etc. (specify)
10. In terms of area, approximately how much does partial (selective) cutting represent compared with clear-cutting in your area of interest?
- 0% 10 20 30 40 50 60 70 80 90 100%
- 11: What is the approximate budget for the acquisition of information pertaining to clearcuts for the time frame you have indicated in question 8?
- a. < \$1000
 - b. \$1000 - \$3000
 - c. \$3000 - \$5000
 - d. \$5000 - \$10,000
 - e. > \$10,000

12. What instrumentation is use to transfer clearcut information to a base map?
- a. zoom transferscpe
 - b. sketchmaster
 - c. Kail plotter
 - d. enlarger-reducer
 - e. photogrammetric plotter
 - f. digitization and computer mapping equipment
 - g. other (specify)
13. By what month must you report information pertaining to clearcuts of the previous year?
14. Which of the following does your compilation and reporting procedure require?
- a. area depleted
 - b. species depleted
 - c. volume depleted
 - d. other (specify)
15. If you have a positional accuracy requirement for mapping of clearcuts please indicate what it is?
16. Has LANDSAT satellite data been utilized for clearcut mapping in your area of responsibility?
- a. yes
 - b. no
17. If yes to 16, to what extent has LANDSAT dat been utilized (i.e. research or operational)? Briefly elaborate.
18. If no to 16, has the utilization of LANDSAT been considered?
- a. yes
 - b. no

19. If no to 16, please indicate why. (Check one or more)

- a. insufficient knowledge of LANDSAT images
- b. insufficient knowledge of how to order images
- c. insufficient knowledge of computer analysis systems and techniques.
- d. insufficient knowledge of visual analysis systems and techniques.
- e. insufficient knowledge of the information content of LANDSAT images.
- f. lack of capability to integrate results with FRI maps.
- g. inadequate information content
- h. unacceptable classification accuracy.
- i. unacceptable positional accuracy
- j. unacceptable format of the final product (i.e. classified image)
- k. cost of computer tapes and analysis too high
- l. cost of photographic products and visual analysis too high
- m. need to acquire air photography for other purposes anyway
- n. we are satisfied with our present system of mapping clearcuts.
- o. administrative reasons
- p. other (specify)

20. If it could be demonstrated that LANDSAT could be used to map forest clearcuts with as much accuracy and as completely as your existing methods, and in a cost effective manner, would such a system be considered:

- a. as a replacement for aerial photography?
 - i. yes
 - ii. no
- b. as a partial replacement in certain areas?
 - i. yes
 - ii. no
- c. as a supplement to aerial photography?
 - i. yes
 - ii. no

21. Under what conditions would LANDSAT be considered as a replacement or supplement to present methods of mapping clearcuts?

22. Additional comments

RESULTS OF QUESTIONNAIRE

	MNR	COMPANIES	TOTAL
	# (%)	# (%)	# (%)
No. Mailed	26	14	40
No. Respond'ts	21 (81)	14 (100)	35 (88)
1. a. yes	21/21 (100)	13/14 (93)	33/34 (97)
b. no	0	0	0
2. a.	21/21 (100)	14/14 (100)	34/35 (98)
b.	10/21 (50)	7/14 (50)	17/35 (48)
c.	3/21 (15)	0	3/35 (85)
d.	0	0	0
e.	0	0	0
f.	8/21 (40)	1/14 (7)	9/34 (26)
g.	0	0	0
3. a.	21/21 (100)	14/14 (100)	35/35 (100)
b.	0	0	0
4. a. yes	20/21 (100)	14/14 (100)	35/35 (100)
b. no	0	0	0
5. a.			
b.)	20/21 (95)	14/14 (100)	34/35 (97)
c. 0	0	0	0
6.	0	0	0
7.	J-2 F-0 M-0 A-3 M-8 J-3 J-0 A-2 S-0 O-1 N-2 D-0	J-0 F-0 M-1 A-3 M-4 J-4 J-2 A-0 S-0 O-2 N-1 D-0	J-2 F-0 M-1 A-6 M-12 J-7 J-2 A-2 S-0 O-3 N-3 D-0
8. a.	10/21 (48)	4/14 (29)	14/35 (40)
b.	11/21 (52)	9/14 (64)	20/35 (57)
c.	0	1/14 (7)	1/35 (3)
d.	0	0	0
9. a.	16/21 (76)	7/14 (50)	23/35 (66)
b.	13/21 (62)	8/14 (57)	21/35 (60)
c.	21/21 (100)	14/14 (100)	35/35 (100)
d.	20/21 (95)	7/14 (50)	27/35 (77)
e.	13/21 (62)	5/14 (36)	17/35 (49)
f.	14/21 (67)	9/14 (64)	23/35 (66)
g.	"site prep"- results integrated with f.		

	MNR	COMPANIES	TOTAL
	# (%)	# (%)	# (%)
10.	0%-4 10-7 20-3 30-4 40-0 50-2 60-0 70-1 80-0 90-1 100%-0	0%-3 10-5 20-2 30-1 40-1 50-1 60-1 70-0 80-0 90-0 100%-0	0%-7 10-12 20-5 30-5 40-1 50-3 60-1 70-1 80-0 90-1 100%-0
11. a.	2/21 (5)	1/14 (7)	8/35 (23)
b.	4/21 (20)	3/14 (21)	7/35 (20)
c.	10/21 (50)	4/14 (29)	14/35 (40)
d.	2/21 (10)	6/14 (43)	8/35 (23)
e.	1/21 (5)	0	1/35 (3)
12. a.	0	0	0
b.	21/21 (100)	10/14 (71)	31/35 (89)
c.	0	0	0
d.	2/21 (10)	3/14 (21)	5/35 (14)
e.	0	0	0
f.	0	2 (artograph)	2
13.	question apparently misinterpreted as question # 7.		
14. a. &	21/21 (100)	13/14 (93)	34/35 (97)
b.	16/21 (80)	10/14 (71)	26/35 (75)
c.	14/21 (70)	7/14 (50)	21/35 (60)
d.	6 (age class site class, working group)	0	6/35 (17)
15.	10-140 m (10 reports)	1-50 m (5 reports)	1-140 m (15 reports)
16 a. yes	0	1/14 (7)	1/35 (3)
b. no	21/21 (100)	13/14 (93)	34/35 (97)
17.	0	0	0
18. a. yes	12/21 (57)	5/13 (38)	17/34 (50)
b. no	8/21 (38)	8/13 (62)	16/34 (47)

		MNR	COMPANIES	TOTAL
	#	(%)	#	(%)
19. a.	4/21		6/13	10/34 (29)
b.	2/21		4/13	6/34 (18)
c.	5/21		4/13	9/34 (26)
d.	6/21		4/13	10/34 (29)
e.	6/21		4/13	10/34 (29)
f.	11/21		3/13	14/34 (41)
g.	4/21		2/13	6/34 (18)
h.	5/21		1/13	6/34 (18)
i.	2/21		2/13	4/34 (12)
j.	2/21		0	2/34 (6)
k.	1/21		2/13	3/34 (9)
l.	2/21		2/13	4/34 (12)
m.	13/21		3/13	16/34 (47)
n.	10/21		6/13	16/34 (47)
o.	3/21		0	3/34 (9)
p.	4/21			4/34 (12)

20. a. i. yes	7/21	(33)	6/14	(43)	13/35	(37)
ii.no	9/21	(43)	8/14	(57)	17/35	(49)
b. i. yes	13/21	(62)	11/14	(79)	24/35	(69)
ii.no	2/21	(9)	2/14	(14)	4/35	(11)
c. i. yes	18/21	(86)	13/14	(93)	31/35	(89)
ii.no	2/21	(10)	1/14	(7)	3/35	(9)

21. cost-effective	5x	5x	10x
accurate	8x	3x	11x
timely and data availability	7x	0	7x
same info as SAP	2x	1x	3x
can map at 1:15,840	2x	0	2x

22. Additional Comments

MNR: - SAP can focus on selected areas on short notice

- need more detail, not less

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Terrace Bay, Ont. POT 2W0

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Sault Ste. Marie District
Ministry of Natural Resources
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Sault Ste. Marie, Ont. P6A 5L5

Forestry Companies Responding to Questionnaire

Chief Forester
Longlac Woodlands
Kimberley-Clark of Canada Ltd.
Longlac Ont. POT 2A0

Chief Forester
QNS Paper Co. Ltd.
P.O. Box 700
Manitouwadge, Ont. POT 2C0

General Manager
Pineland Timber Co. Ltd.
P.O. Box 1791
Espanola, Ont. POP 1C0

L. Bennett
Ontario Paper Co. Ltd.
10 Harold Ave.
S. Porcupine, Ont.

Vice President, Woodlands
Operations
Spruce Falls Power and Paper Co.
Ltd.
P.O. Box 100
Kapuskasing, Ont. P5N 2Y2

Chief Forester
Waferboard Corporation Ltd.
P.O. Box 1100
Timmins, Ont.
P4N 7H9

Divisional Woods Manager
Abitibi-Price Inc.
Iroquois Falls Division
Iroquois Falls, Ont. P0K 1E0

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Resident Manager
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Chief Forester
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General Manager, Ontario
Woodlands
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APPENDIX B

COMPARISON OF THEMATIC MAPPER WITH
SUPPLEMENTARY PHOTOGRAPHY FOR COMBINED ATTRIBUTES

The attributes of remote sensing data deemed important by the foresters surveyed in northern Ontario were ranked by a method for rating competing technologies. The rating system was developed by Stern et al, (1976). The method was adopted in order to compare objectively LANDSAT Thematic Mapper (TM) and supplementary aerial photography (SAP).

A total of seven key attributes were selected for comparison. The attributes were rated according to the following scale:

Rating Scale For Attributes

- 3 - the product possesses this attribute to a high degree
- 2 - the product possesses this attribute to a considerable degree
- 1 - the product possesses this attribute to a limited degree
- 0 - the product does not possess this attribute

The attributes of the competing remotely sensed data sets are then rated according to their perceived importance as expressed by the foresters operating in Northern Ontario. Some of the ratings such as low cost and timeliness of acquiring data have been inferred from the answers to the questionnaire.

Rating Scale for Importance of Attributes

- 16 - critical
- 8 - very important
- 4 - somewhat important
- 2 - of little importance
- 0 - of no importance

The ratings for the attributes are multiplied by the importance ratings. The resultant figures are added to give an utility factor for the competing technologies. The conventional technology is normalized to 1.

The attributes, attribute and importance ratings and results are presented in the table below. The resultant

utility rating for TM is .88 compared with the normalized rating of 1 for SAP.

The TM received equal ratings for factors deemed critical, namely integration with FRI maps and completeness of interpretation. The TM received higher ratings than SAP for the attributes of low cost and positional accuracy; attributes rated somewhat and very important respectively. The TM received a lower rating than SAP for the attributes of flexibility of data, data availability and timeliness; all of which were given a very important or somewhat important rating.

ATTRIBUTE	TM RATINGS		SAP RATINGS		IMP.
	ATT.	IMPORT.	ATT.	IMPORT.	
INTEGRATION WITH MAPS	3	48	3	48	16
COMPLETENESS	3	48	3	48	16
POSITIONAL ACCURACY	2	16	1	8	8
FLEXIBILITY OF DATA	1	8	3	24	8
LOW COST	3	24	2	16	8
TIMELINESS	2	8	3	12	4
DATA AVAILABILITY	1	8	3	24	8
UTILITY RATING	160		180		
NORMALIZED RATING	.88		1		

END

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