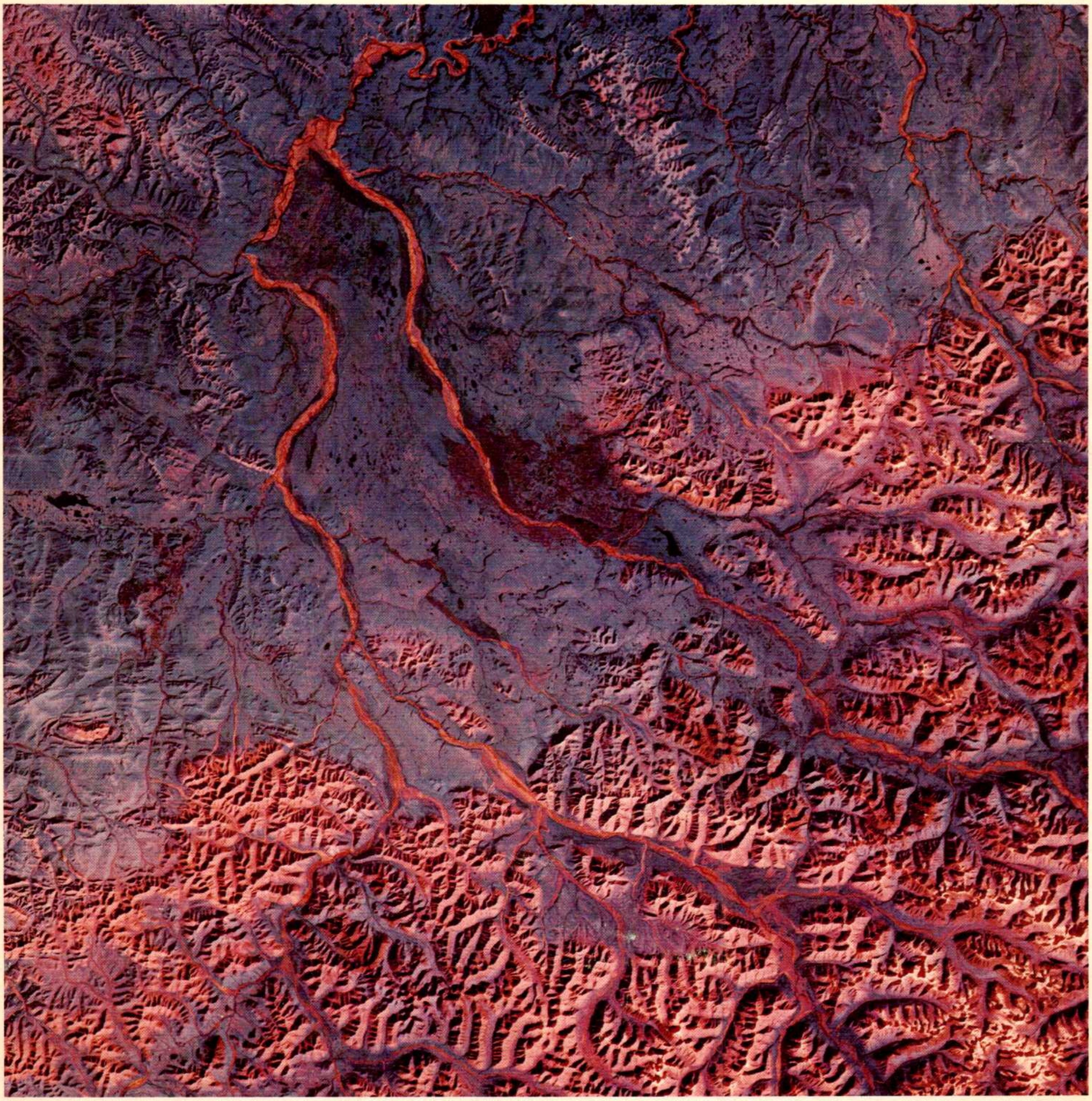
ECOLOGICAL (BIOPHYSICAL) LAND CLASSIFICATION IN CANADA

CLASSIFICATION ÉCOLOGIQUE (BIOPHYSIQUE) DU TERRITOIRE AU CANADA



Ecological Land Classification Series, No. 1

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AN EVALUATION OF REMOTE SENSING TECHNIQUES FOR ECOLOGICAL (BIOPHYSICAL) LAND CLASSIFICATION IN NORTHERN CANADA

J. Thie
Lands Directorate
Environment Canada
Ottawa, Ontario

ABSTRACT

The use of LANDSAT satellite and airborne remote sensing imagery are evaluated in a sub-arctic and northern boreal environment near Churchill, Manitoba. Accuracy and cost-effectiveness of a number of interpretation methods are compared, including visual and automated (supervised and unsupervised) techniques of LANDSAT data and air photo interpretation. Classification results of the different techniques are compared by using the overlay capabilities of the Canada Geographic Information Computer System. Conventional interpretation of aerial photographs enabled classification of about 43 different land types, and proved the best and most practical method for comprehensive biophysical mapping. Satellite-based methods allowed the mapping of about 10 groups of land types, often so broad that their practical value for resource management is limited. At present, visual satellite interpretative methods are more cost-effective than automated approaches for ecological land classification in most parts of Canada.

RÉSUMÉ

L'emploi de satellites de LANDSAT et d'images obtenues par télédétection aérienne est évalué dans un milieu subarctique et boréal près de Churchill, au Manitoba. L'exactitude et le rapport coût-efficacité d'un certain nombre de méthodes d'interprétation, y compris les techniques visuelles et automatisées (avec ou sans surveillance) d'interprétation des données LANDSAT et de photo-interprétation, sont comparées. Les résultats de la classification des diverses techniques sont comparés par l'exploitation des possibilités de recouvrement de l'ordinateur du système d'information geographique du Canada. L'interprétation classique des photographies aériennes a permis de classer environ 43 types de terrains, et s'est avérée la meilleure et la plus pratique des méthodes de cartographie biophysique. Les méthodes utilisant les satellites ont permis de dresser des cartes d'environ 10 groupes de types de terrains, souvent si généraux que leur applicabilité à des fins de gestion des ressources est limitée. A l'heure actuelle, les méthodes visuelles d'interprétation des images prises par satellite sont plus efficaces, relativement au coût, que les méthodes automatisées en ce qui concerne la classification écologique des terres dans la plupart des régions du Canada.

INTRODUCTION

Environmentally sound resource management requires basic biological-physiographical and socioeconomic data that allow an integrated or multidisciplinary approach. In the southern developed part of Canada, the Canada Land Inventory Program has provided a multidisciplinary land capability mapping. One-third of our land area is covered with this nationally consistent information base. For about 3.5 million km^2 of land in the north, there is a serious lack of such base line data (Romaine, 1974).

The National Committee on Forest Land, working under the auspices of the Canada Land Inventory Program, recognized this gap in environmental data and through its subcommittee, started the development of a classification system to provide this biological-physiographical data base for 'wildlands'. The biophysical land classification system evolved. The further development of this system is now supported by the Canada Committee on Ecological (Bio-physical) Land Classification.

The aim of the classification system is to differentiate and classify, at a small scale, ecologically significant segments of the land surface (Lacate *et al.*, 1969). It was recognized that this system should be ecolog-

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ically based, and that mapping and the description of land surfaces, and assessments related to forestry, wildlife, recreation, agriculture, etc., could be made rapidly and with little additional effort. The system has four levels in its classification hierarchy. *Land region,* the first level, is defined as an area of land characterized by a distinctive regional climate as expressed by vegetation. The second level, *Land district,* is basically a sub-division of the land region based primarily on the separation of major physiographic and/or geologic patterns that characterize the region as a whole. *Land system,* the third level, is defined as land areas throughout which there is a similar recurring pattern of landforms, soils and vegetation. The fourth level, *Land type,* could also be called a land ecosystem. It has a fairly homogeneous combination of soil and chronosequence of vegetation. Mapping scales suggested are as follows:

Land Region	1:1,000,000	- 1:3,000,000
Land District	1:500,000	- 1:1,000,000
Land System	1:125,000	- 1:250,000
Land Type	1:10,000	- 1:20,000

The objective of this paper is to report on the usefulness of airborne and satellite remote sensing for biological-physiographical data gathering in northern areas. As low cost and rapidity are considered critical, most attention is given to the evaluation of LANDSAT data. Different interpretation methods are tested in an area near Churchill, Manitoba, where boreal and arctic elements are present.

Air photo interpretation has played a significant role in the development of environmental survey systems related to vegetation, surficial geology, soils, forestry and agriculture including biophysical land classification. In the early 1950's, Hills recognized the value of aerial photographs for his forest site (physiographic site) classification. He stressed landform and surface geology as the integrating framework for vegetation, soils, local climate and 'site'. The value of landforms in delineating and describing site conditions was supported by Gimbarzevsky (1966) and Lacate (1966). Stereoscopic viewing of aerial photographs provides a three-dimensional image of terrain features. Relief and slope are important indicators of ecosystem parameters such as drainage, parent material, soil formation and vegetation succession (Thie, 1972). Good perception of depth in a stereo model and quick analysis of shapes and textures enable the human interpreter to readily separate significantly different units. Following field descriptions of selected sample areas, results can be extrapolated to non-sampled similar areas by means of photo-interpretation. With this approach, the total number of field investigations is considerably less than in conventional surveys. The value of each field observation is much greater; therefore, both its choice location, and its description and classification are more critical (Vink, 1964).

As a result of the development of new remote sensors, the interpretation methodology is changing rapidly. Much of the 'imagery' generated by airborne and satellite sensors is now stored in an analogue or digital fashion on magnetic tape. Transforming these into visible images for human interpretation usually significantly reduces spectral information and spatial resolution. Computer interpretation of images should not entail loss of information.

The introduction of the airborne program of the Canada Centre for Remote Sensing (CCRS) and the launch of the Earth Resources Technology Satellites (ERTS, presently called LANDSAT) pushed the research in application of remote sensing in Canada rapidly ahead. Much of the work, at one time carried out in the U.S., now came within reach of Canadian researchers. These Canadian experimenters in remote sensing-assisted soil mapping, terrain studies and biophysical inventories (Beke, 1972; Boydell, 1974; Desloges, personal communication; Gimbarzevsky, 1974; Howarth, 1976; Mills, 1972; Oswald, 1975; Tarnocai, 1972; Tarnocai and Thie, 1974; Thie, 1972, 1976; and Thie *et al.*, 1974) used visual and automated methods of analysis.

STUDY AREA

To evaluate airborne and satellite remote sensing for northern land classification, an area was chosen in that part of northern Manitoba where arctic and boreal elements meet (Figure 1). Two main physiographic regions also meet in this area - the Canadian Shield and the Hudson Bay Lowland. In this area, the disturbance of natural vegetation by man and fires is insignificant; surface vegetation can be considered as a good indicator of subsurface conditions, and therefore also of the geographic distribution of land types or ecosystems.

Using LANDSAT imagery, the area was subdivided into two land regions and five land districts (Figure 1). Although the boundary of the land regions is actually based on a physiographic divide, the difference in the first place is climatic. This climatic difference is expressed in the distribution of

Figure 1: Land districts in the Churchill map-sheet (54L). The square area outlined in heavy lines represents the 54L sheet. Background is an image taken 14 Aug. 1973 (1387-17021-band 7). Continuous lines delineate the land districts; broken, the 'transition' zones.

vegetation and permafrost occurence.

LAND REGION (1) has continuous and widespread discontinuous permafrost (Brown, 1967), a prevalent forest-tundra type of vegetation (Ritchie, 1962), and an arctic climate.

The *Seal River District* (1A) is characterized by a relatively thin layer of stony till over bedrock, partly overlain by extensive peat deposits. Water-modified glaciofluvial deposits, till ridges, and beaches occur throughout the area. Till covers about 35% of the area. In wet to moist areas, strong frost heaving of stones and rocks in the till has resulted in rock and stone fields. In the peatlands, peat polygons occur, as well as sedge wetlands.

The *Lofthouse-Lovett Lake District* (1B) consists of 99% organic deposits over marine sediments and till. Glaciofluvial deposits provide the only areas of dry land. In the peatlands, peat polygons occur more frequently (40%), associated with patterned sedge fens (30%).

The *Coastal District* (1C) is the most complex district in the study. This narrow strip along the coastline consists of extensive marine flats, alluvial deposits, numerous beach ridges, and a thin layer of relatively recent organic deposits. Occasional bedrock and glaciofluvial deposits are found. Wetland types are sedge fens, peat plateaus, palsas and salt marshes.

LAND REGION (2) is marked by widespread discontinuous permafrost, open coniferous forest and a north boreal and arctic climatic.

In the *Mack Lake District* (2A), more than 95% of the surface material is peat. Peat plateaus form the dominant landforms reflecting the gently undulating topography controlled by a thick overburden of till over Precambrian bedrock.

In the *Knife River District* (2B), till is the dominant surface material. It has a vegetation cover of open to semi-open black spruce. Local fires may have introduced jack pine. Only about 20% of the area is covered with peat (peat plateaus and sedge fens).

METHODS

Fieldwork, carried out during the summers of 1973 and 1974, entailed an aircraft survey and the sampling of landform-soil-vegetation-permafrost complex in about 100 locations.

Remote sensing photography, including high altitude coverage for the complete study area and low altitude and radar coverage for selected parts of the area, was obtained on different dates during the spring and summer of 1973. The standard sensor package included colour infrared, colour, and black and white photography combined with various filters, and thermal infrared scanning (Figure 2). Moreover, various LANDSAT images in the form of prints, transparencies and digital tapes were used in the satellite evaluation

To compare the effectiveness of various visual and automated satellite interpretative techniques, three different ecological land classification maps were prepared:

MAP I - based on the visual interpretation of 1:1,000,000 multidate LANDSAT imagery.

MAP II - based on the visual interpretation of a LANDSAT colour composite, digitally enlarged to 1:250,000 scale.

MAP III - based on a supervised automated interpretation using the Multispectral Analyser Display (MAD) of the CCRS.

In addition, parts of the study area were mapped using unsupervised automated classification techniques and supervised and unsupervised multidate (summer-winter combination) interpretation techniques as implemented on CCRS Image 100 and MAD systems.

To measure the success of each map, it was compared with a detailed ecological base map. This map is based on field sampling and visual interpretation of 1:100,000 scale black and white aerial photographs.

Based on field work, about 50 representative land types were recognized. They formed the legend for classification of map units (or pixels) for any of the interpretative methods. For convenience, these are called *classes*. Grouping of classes into *class groups* was done when the land types were not spectrally separable, or were cartographically or resolution-wise unmappable. A simple alphameric system was used to identify the classes.

To allow easy comparison of the interpretative results, all ecological land classification maps were stored in the Canadian Geographic Information System (CGIS) of the Lands Directorate, Department of the Environment, Ottawa. This system is designed to read, store, analyse, manipulate, and overlay maps. Using this system, Maps I and II were overlaid on the detailed ecological base map. For each mapping on both maps, a new classification was generated using the detailed base, and the results were compared with the original classification of the units. The amount of misclassification was calculated as the difference from the base map for each class and class group on a land system (Table 1), land district and total map sheet basis. The individual performance of mapping units and classification generated by the different methods are measured on a land system basis; the relation of classification performance and physiographic and ecological characteristics are obtained through the land district analysis. Because of geometric distortions, Map III was visually compared with Map IV and detailed aerial photographs.

RESULTS

The maps generated by the visual interpretation methods are partly displayed in Figure 3. The results of the supervised automated classification are displayed in Figure 5. To compare the various maps, at least four aspects have to be considered.

1. The number and size (detail) of the units on the map.
2. The number of land types (ecosystems) that are used in the legend.
3. The classification accuracy of the mapping units.
4. The accuracy or significance of the land system (mapping unit) boundaries.

On the ecological base map, 700 land systems were mapped, each covering about 1800 ha. Map II, resulting from the visual interpretation of 1:250,000 satellite imagery, has 167 land systems for three areas covering about 25% of

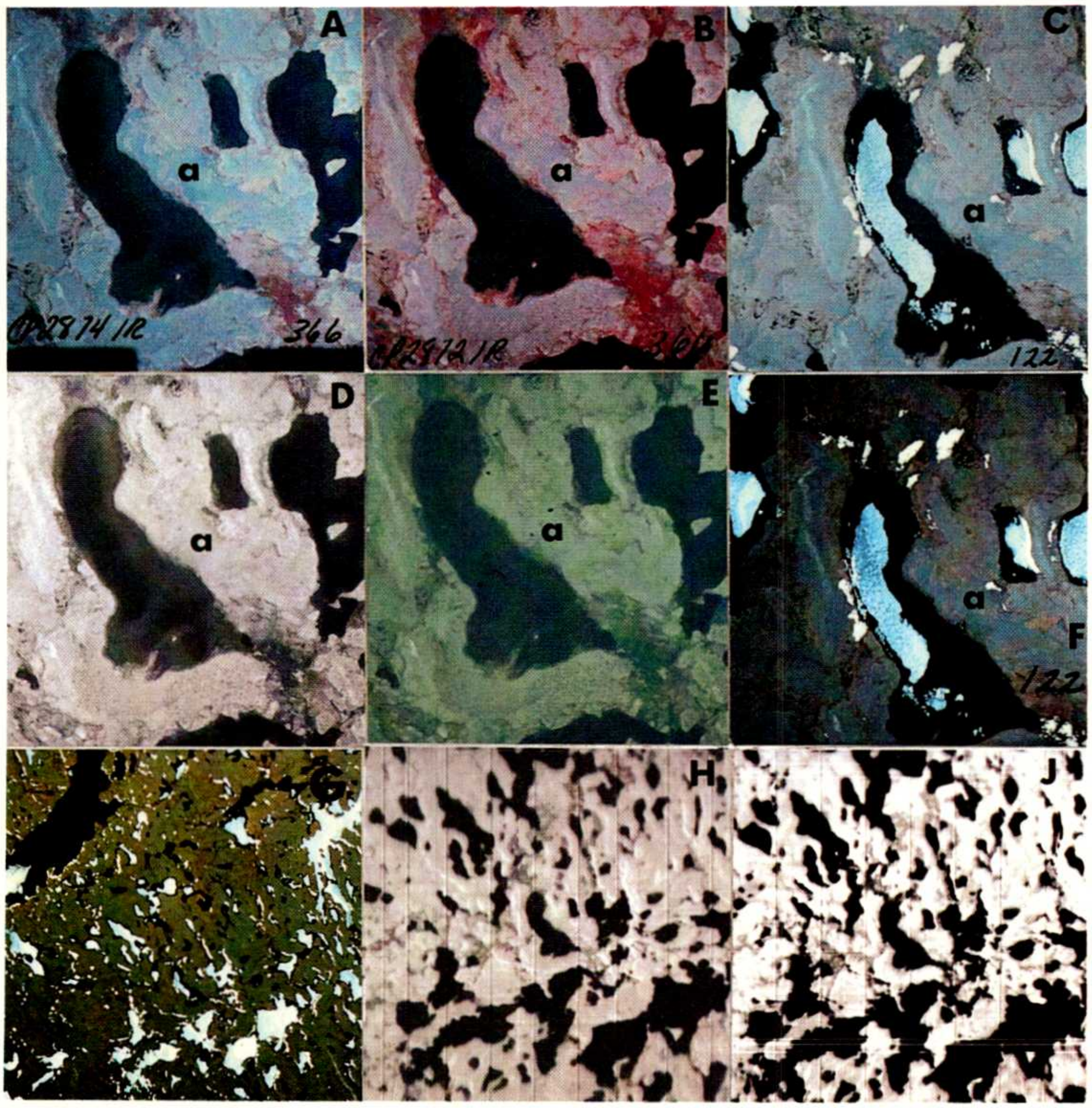

Figure 2: Airborne multiband coverage of the Long Lake area. Two flights took place at an altitude of 3,050 m ASL. A, B, D, E *and* H *were taken 22 July 1973;* C, F, G *(at 10,700 m ASL) and* I *were taken 1 June 1973.* A *(CP28741R-366) was taken with a 2443 film with CC20M filter;* B *(CP28721R-366) with a CC20B filter;* D *(BN2873-366) with a 2405 film combined with a W~~12~~* 25 *filter ('Red Band') and* E *(CP2875-366) a colour photo.* H *and* I *are thermal scanning images taking simultaneously with the 70 mm Vinten camera imagery.* G *(RSPA-306651R) is part of a 9" by 9" small scale colour infrared photo.*

Table 1: Computer-Generated Overlay Results. In this example of computer-generated overlay results, Maps I and IV, the land system (no. 543300003) is described by two columns with classes. The left column shows the method to be tested (Map I); the right column shows the 'true' classification based on (Map IV).

	MAP I			MAP IV			difference			
LANDSYSTEM 543300003	CLASS	AREA	%	CLASS	AREA	%	AREA	%		%
	A3	31593	60	A1	3888	7	3888	7	A	3.0
				A3	16629	32	-14964	-28		
				A31	12670	24	12670	24		
				B1	600	1	600	1		
	B2	10531	20				-10531	-20	B	-18.9
				C2	4007	8	4007	8	C	7.6
				D1	104	0	104	0	D	6.3
				D2	174	0	174	0		
				D3	791	2	791	2		
				D5	2225	4	2225	4		
	E1	10531	20	E1	7354	14	-3176	-6	E	-6.0
				G1	1501	3	1501	3	G	6.0
				G12	523	1	523	1		
				G2	1133	2	1133	2		
				02	214	0	214	0	0	1.6
				03	644	1	644	1		
				P1	196	0	196	0	P	0.4
				TOTAL	52655	100		53.5		24.9

the total map area; coverage size is 2370 ha. Map I, based on 1:100,000 LANDSAT imagery, has 149 land systems averaging about 9100 ha. Thus, the levels of mapping detail of Maps II and IV are similar; Map I, however, displays significantly larger units.

1:1,000,000 Visual Satellite Interpretation

Figure 4 shows the classification results for each land system as mapped on 1:100,000 multidate satellite images (Map I) as compared with the base map (Map IV). The percentages in the map units identify the amount of misclassification for each land system. The lower number gives the weighted sum (based on averages) of the misclassification for individual classes or land types (A_1, A_2, A_3, B_1, B_2, etc.). The upper number gives this weighted sum of misclassification for groupings of the individual classes (A, B, C, D, etc.) for that land system. Misclassification for each class group of classes is based on the areas of omission per class or per class group by land system as a percentage of land area. For example:

$$100 \times \frac{\text{CLASS Y acreage (Map IV)} - \text{CLASS Y acreage (Map I)}}{\text{land system acreage}} = \text{\% omission of Y}$$

and

$$\text{Land system misclassification} = \frac{\Sigma[\text{\% of omission (A), (B), (C),...(Z)}]}{2}$$

As shown by the lower numbers on Map V (Figure 4), the amount of misclassification arising from visual interpretation of individual land types is excessive in most areas. The best system has 21% misclassification. Only 11 of the 149 land systems have better than 35% misclassification. This indicates that the land type legend used for visual interpretation is too complicated for this method as it causes excessive classification errors. Simplifying the legend by joining land types into groups of classes (A, B, C, etc.) increases classification accuracy significantly (upper number, Figure 4) to the extent that 58 of the 149 units have acceptable classification results.

Figure 4 shows that relatively large amounts of misclassification occur in the smaller and more complex land systems. It illustrates a relationship between physiographic complexity and the amount of misclassification. The greatest amount of misclassification is found in areas where mineral deposits occur. While peat-dominated areas, such as the peat plateaus in the SW part of the map area, have relatively good classification results (5%-20% misclassification), till-dominated areas nearby in land region 2 are misclassified by as much as 90%. However, mineral soils in land region 1 are significantly better-classified (about 30% misclassification). This possibly arises from the relative lack of vegetation and the lack of vegetation disturbance in the area, which results in less confusion during interpretation. Figure 4 also shows that higher amounts of misclassification are associated with the coastal

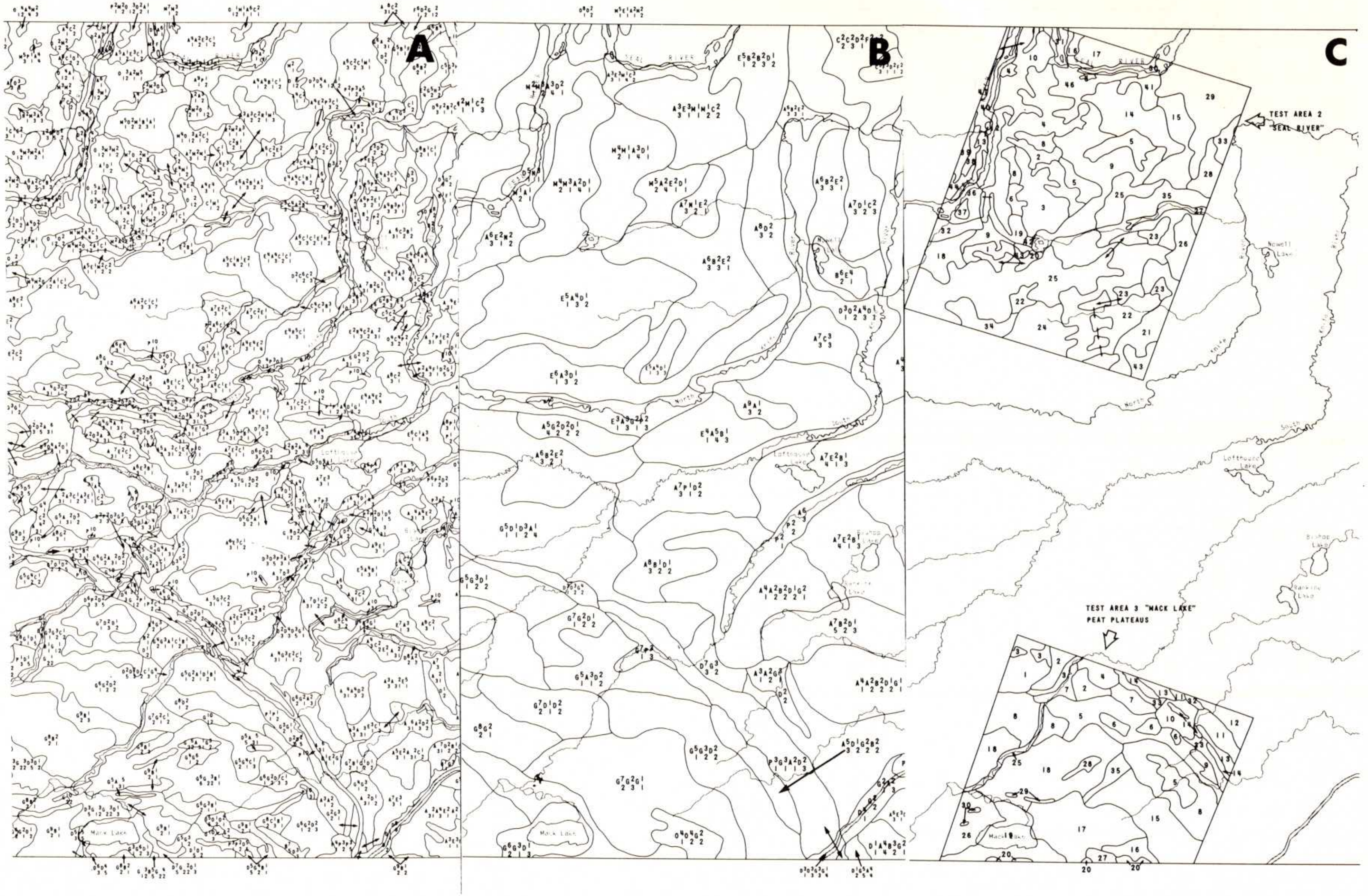

Figure 3: *Visual interpretative methods.* A *shows part of the detailed ecological base map;* B *is the same area interpreted from 1:1,000,000 LANDSAT imagery; and* C *shows parts interpreted from 1:250,000 scale enlarged LANDSAT images.*

COMPARISON OF CLASSIFICATION RESULTS

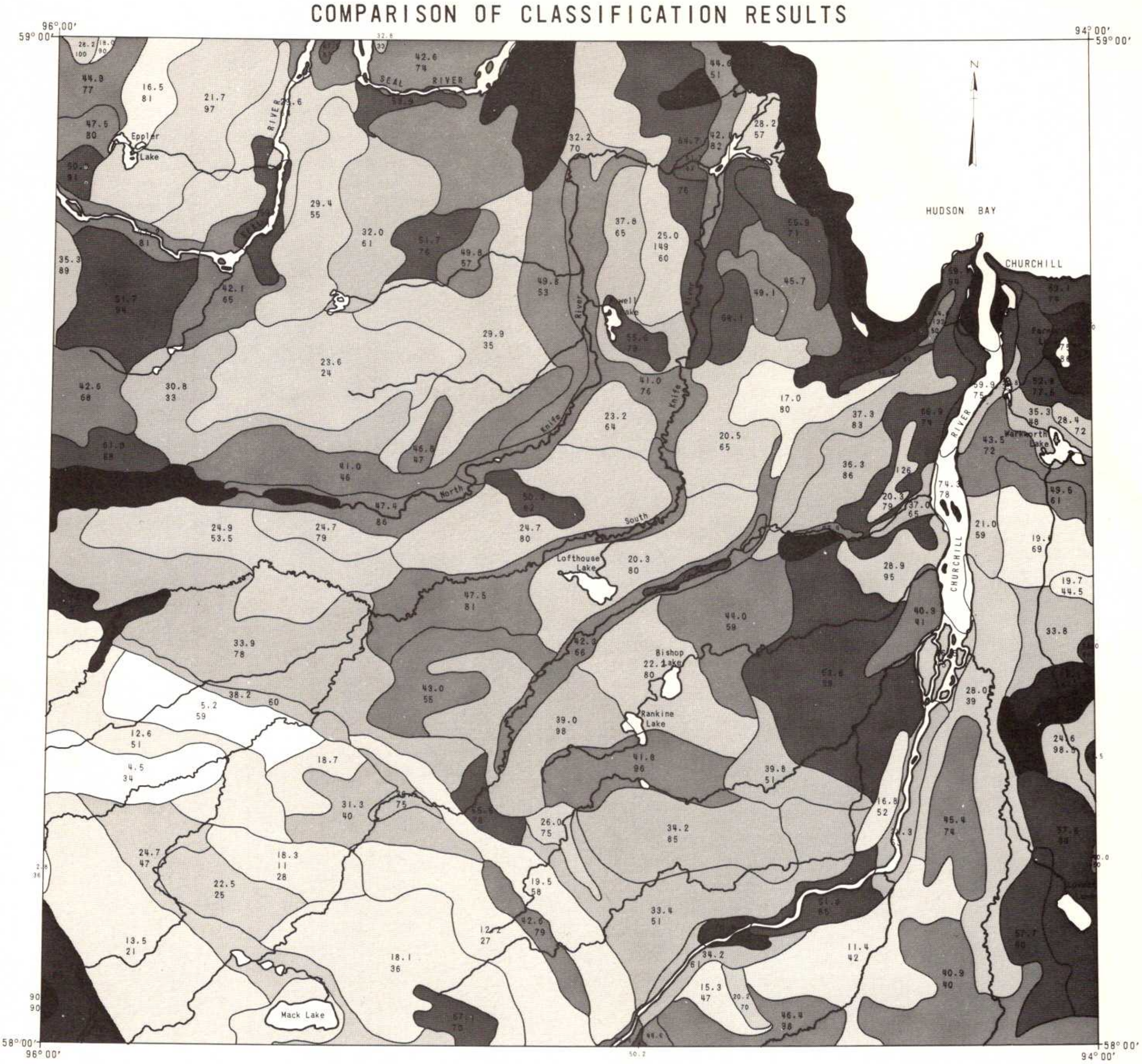

Figure 4: Map V - a comparison of classification results. Map I was overlaid on the biophysical base map (Map IV) and misclassification of Map I was calculated for each land system using the Canadian Geographic Information Computer System. The upper number gives the misclassification per land system when the various land types are grouped into broader class groups (A, B, C......Z), while the lower number lists the misclassification per land system when individual land types are compared (A_1, A_2, A_3,......B_1, B_2,.....C_1, etc.). Scale - 1:750,000.

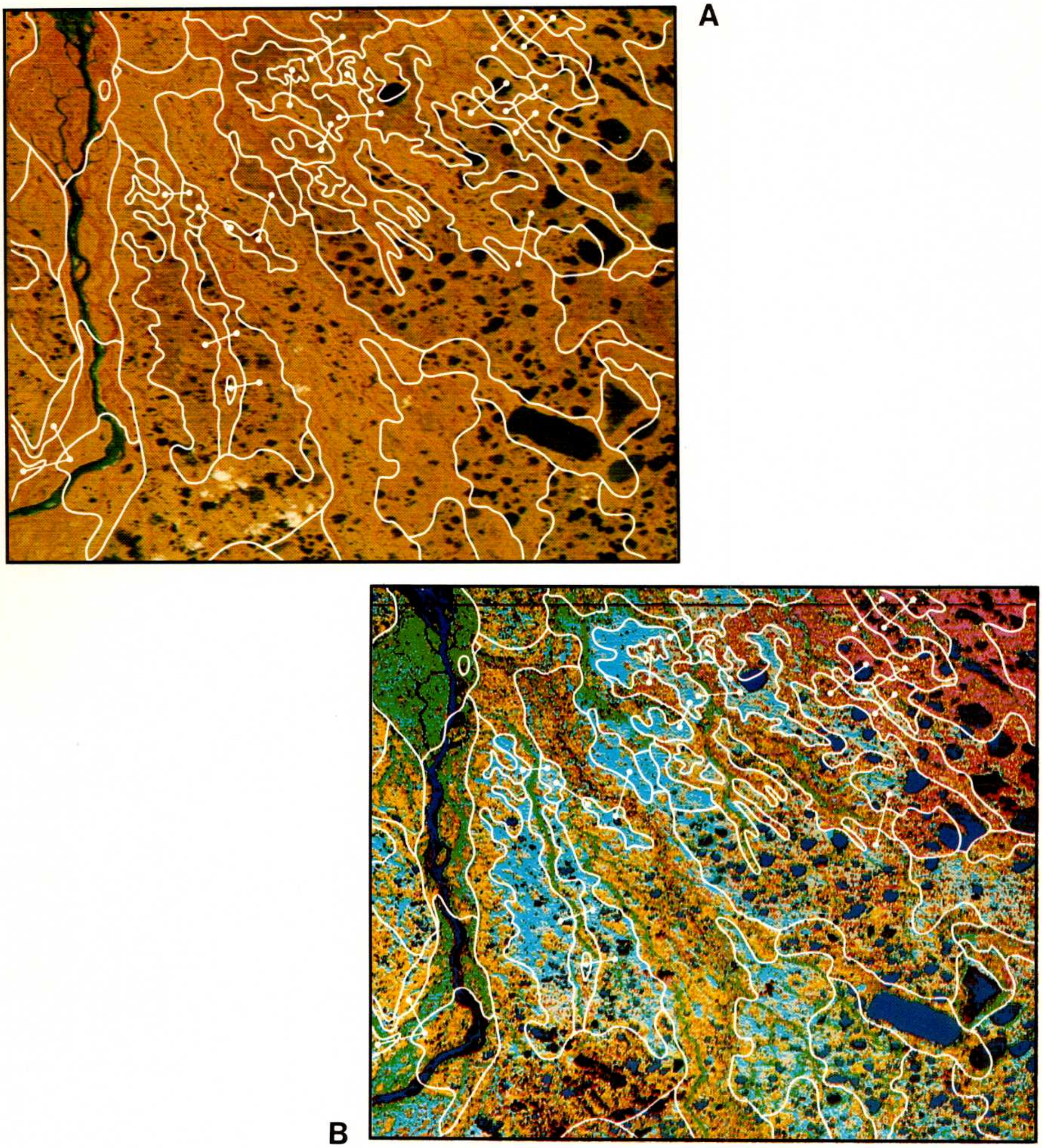

Figure 5: The Lovett Lake test area. A is the digitally enlarged satellite colour composite, with delineation of land system by visual interpretation. B is the result of supervised automated classification. For comparison, the land system lines of A are superimposed on B. While there is a good general relationship between the two sets of information, there are some discrepancies in areas where cloud cover or slight haze interferes (arrows). Such interference is difficult to eliminate with automated techniques.

	TOTAL MAPSHEET			BY DISTRICTS																																	
				MACK LAKE DISTRICT (2A)				KNIFE RIVERS DISTRICT (2B)				TRANSITION DISTRICTS 2 and 1				SEAL RIVER DISTRICT				LOFTHOUSE - LOVETT LAKES DISTRICT												COASTAL DISTRICTS			
																				TRANSITION 1B and 2A&B				DISTRICT 1B				TRANSITION (2) and 1C							
CLASS	omission as % of class	omission as % of area	total of class as % of map	omission % of class	omission % of district	% of district	% of map	omission % of class	omission % of district	% of district	% of map	omission % of class	omission % of district	% of district	% of map	omission % of class	omission % of district	% of district	% of map	omission % of class	omission % of district	% of district	% of map	omission % of class	omission % of district	% of district	% of map	omission % of class	omission % of district	% of district	% of map	omission % of class	omission % of district	% of district	% of map
A	1.4	0.4	29.0	-6	0.0	1	0.1	23	2.6	11	0.3	19	5.4	28	0.8	19	7.7	40	3.4	11	3.4	30	3.6	-4	-2.0	49	18.2	-6	-1.5	27	2.6	22	0.3	1	0.1
B	-78	-3.3	4.2	98	8.3	8	1.0	69	1.8	3	0.1	100	0.0	0	0.0	75	0.9	1	0.1	-188	-3.0	2	0.2	-336	-8.5	2	0.9	-21	-1.8	8	0.8	-59	-6.9	12	1.2
C	46	3.2	6.9	100	0.8	1	0.1	100	1.9	2	0.0	59	4.7	8	0.2	-74	-4.7	6	0.5	100	4.3	4	0.5	61	5.2	8	3.2	30	+3.5	11	1.1	41	5.3	13	1.3
D	-13	-1.0	8.0	10	1.3	13	1.6	84	26.6	32	0.7	48	5.4	11	0.3	-144	-5.3	4	0.3	-63	-8.3	13	1.6	0	0.0	7	2.5	-25	-1.2	5	0.5	-57	-3.3	6	0.6
E	33	4.4	13.0	5	0.0	0	0.0	-51	-0.7	1	0.0	7	0.4	5	0.1	-34	-2.2	6	0.5	85	5.1	6	0.7	26	6.5	25	9.7	65	11.6	18	1.7	91	4.0	4	0.5
F	-60	-0.9	1.5	-	-	-	-	-	-	-	-	100	0.4	0	0.0	+100	0.1	0	0.0	-	-	-	-	75	0.1	0	0.0	-123	-2.1	2	0.2	-57	-7.1	12	1.3
G	-5	-1.1	20.7	-11	-8.4	74	8.6	8	2.3	29	0.6	-1685	-3.2	2	0.0	-	-	-	-	-0.6	-0.3	39	4.7	-3	-0.1	4	1.7	-40	-9.8	24	2.3	35	9.5	27	2.7
H	-261	-0.6	0.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	0.3	0	0.0	94	0.0	0	0.0	-109	-0.9	1	0.1	-549	-5.6	1	0.1
I	-551	-1.2	0.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	493	-10.6	2	0.2
M	-22	-0.6	2.7	-	-	-	-	-42	-0.6	1	0.0	26	5.1	20	0.6	-34	-8.0	23	2.0	-	-	-	-	-100	-0.2	0	0.1	-100	0.3	0	0.0	100	0.0	0	0
N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
O	-17	-6	3.6	-9	-0.3	2	0.3	-119	-22.2	19	0.4	-98	-21.7	22	0.6	49	7.8	16	1.3	85	1.0	1	0.1	+5	0.1	2	0.7	30	-0.3	1	0.1	-110	-1.1	1	0.1
P	-29	-0.5	1.8	-199	-1.0	1	0.1	-427	-7.8	2	0.0	100	2.1	2	0.0	100	2.9	3	0.3	-55	-2.4	4	0.5	-81	-1.3	2	0.6	100	0.9	1	0.1	70	1.5	2	0.2
R	66	0.2	0.3	-	-	-	-	100	0.1	-	-	100	1.3	1	0.0	100	0.7	1	0.1	-	-	-	-	100	0.0	0	0.0	100	0	0	0.0	5.6	1.5	2	0.2
Z	21	1.5	7.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	1.3	1	0.1	81	13.0	16	1.6
TOTALS			99.7			100	11.8			100	2.1			100	2.6			100	8.5			100	11.9			100	37.2			100	9.5			100	10.2
% misclass. A		9.8			-10.1				35.3				24.9				20.2				14.1				12.0				18.2				35.1		
% misclass. B		29.9			14.7				47.6				42.1				28.1				27.7				33.3				35.1				55.0		

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Table 2: Summary of misclassification per land district and for the total map area based on the results of the visual interpretation of 1:1,000,000 LANDSAT imagery. The class groups can be described as follows: A - Peat polygonal areas; B - Carex *fens; C -* Larix *fens; D -* Picea*-dominated peatlands; E - Patterned fen areas; F - Marshes and swamps; G - Peat Plateaus; H - Palsas; I - Mud flats; M - Stone fields; N and O - Glacial till; P - Sandy beach and glaciofluvial deposits; R - Bedrock outcrop; Z - Water.*

zone and with some drainage and beach systems.

To study these physiographic aspects in more detail, the computer comparison of Maps I and IV for the land districts and the total map area is summarized in Table 2. Listed are:

(i) The omission per class group (A, B, C,......Z) as a percentage of the class group.
(ii) The omission per class group as a percentage of the district or map sheet.
(iii) The actual area of the class group as a percentage of the district.
(iv) The actual area of the class group as a percentage of the map sheet.

The percentage of *misclassification A* is calculated by adding the absolute values of (ii) and dividing by two.

The classification results per land district and map area in this summary table are significantly lower than those identified for the separate land systems (Figure 3). Apparently, errors are cancelled out in the summation process. For example, in the Mack Lake District, misclassification A is 10.1% while Figure 3 shows that most land systems in this district have significantly higher amounts. To obtain a more accurate indicator, the classification performance for each land system was weighted according to acreage and summarized; it is called *misclassification B*.

$$\textit{misclassification B} = \frac{\Sigma[\textit{misclass. (A) for each land system} \times \textit{acreage}]}{\textit{Land district acreage}}$$

Table 1 shows that the Coastal and Knife Rivers districts have the poorest classification results, followed by the transition zones of districts (1B-1A) and (1B-1C). All three areas are physiographically complex. The relatively simple 'Mack Lake' district has the best classification performance: misclassification A is 10.1% and misclassification B is 14.7%. About 74% of this district is composed of peat plateaus. These are only 3.4% overclassified, mainly at the cost of sedge-dominated areas (class B) which as a result of generalization are consistently underclassified.

The Lofthouse-Lovett Lakes district and the Seal River district perform equally well on a land system basis, in spite of the fact that the Seal River area contains a significant proportion of mineral deposits (39% M and O). In both districts, peat polgons represent a large part of the unit (between 30% and 50%) and are consistently well-classified. In the Seal River district, the classification of patterned fens and stone fields is reasonably satisfactory (34% omission). In the latter, it is thought that the lack of vegetation on M (stone fields) has helped to identify the land types. Considerable confusion with O (till areas) is expected, as classes M_2 and M_3 include parts of O.

1:250,000 Scale LANDSAT Visual Interpretation

Table 3, showing the classification results for the Mack Lake, Seal River and Lovett Lake test areas, is similar to Table 2. From the results of misclassifications A and B, the detailed interpretation clearly does not compare well with the results of Map I based on 1:1,000,000 LANDSAT interpretation. The Map I results are clearly equal to or better than Map II results. Although delineation of a land system at the detailed scale is more accurate, it is not matched by a similar increase in classification accuracy. The interpretation time involved for Map II is only slightly less than that required for interpretation of aerial photographs.

	MACK LAKE			SEAL RIVER			LOVETT LAKE		
CLASS	omission as % of class	omission as % of area	total of class as % of area	omission as % of class	omission as % of area	total of class as % of area	omission as % of class	omission as % of area	total of class as % of area
A	-408	-16.0	3.9	25	9.5	38.0	16	6.6	41.8
B	-29	-1.7	5.8	-54	-12.5	23.1	-5	-1.9	41.1
C	-371	-5.4	1.4	19	2.0	10.7	-157	-4.4	2.8
D	54	6.2	11.5	7	0.2	3.4	9	0.1	8.5
E	-	-	-	-	-	-	-	-	-
F	-	-	-	-292	0.2	0.1	31	0.3	0.9
G	+20	14.8	73	-8756	-2.8	0.0	-14	-0.5	3.8
H	-	-	-	-	-	-	-	-	-
I	-	-	-	-	-	-	-	- 0.2	-
M	-	-	-	-11.0	-1.6	15.0	-	-	-
N	-	-	-	-	-	-	-	-	-
O	70	1.1	1.5	49	4.1	8.3	100	0.5	0.5
P	3.5	1.0	2.9	100	0.7	0.7	100	0.0	0.0
R	-	-	-	100	0.5	0.5	-	-	-
Z	-	-	-	-	-	-	100	0.3	0.3
Total	na		100	na		99.8	na		100.0
% misclass A		23.1			16.9			7.1	
% misclass B		38.2			33.4			26.2	

Table 3: Summary of classification results for the three tests areas based on the results of 1:250,000 scale visual satellite interpretation.

AUTOMATED SATELLITE CLASSIFICATION

There are two different approaches to automated classification: supervised and unsupervised. Each was applied to single- as well as multidate satellite imagery. LANDSAT I tapes RS0198 and RS035 were used; moreover, summer and winter data are combined using band 7 of RS2863 (30 October 1972) and bands 5, 6 and 7 of RS2940 (27 July 1972).

Supervised Automated Classification

In supervised classification, the interpreter selects the objects to classify and identifies training areas for the computer. Training areas were selected across the whole image by available ground control and photo-interpretation. This procedure allows the selection of relatively large, pure and representative sites for the respective land types. Classification was carried out using the CCRS computer, MAD (Multispectral Analyser Display) and the MICA interpretation package, developed by scientists at the CCRS. For the classification, the Maximum Likelihood Decision Rule was used in all evaluations, as implemented on the CCRS computer. After about 15 iterations of training, displaying, classifying and analyzing training statistics, a final training set evolved. This set, including water, represents 10 different class groups.

Table 4 shows the divergence and confusion matrix for the class statistics, and the final set. An increase in the number of classes was found to increase confusion and to give less satisfactory results. Initially, in the training process, an attempt to show land types (A_1, B_1, B_2, C_3, etc.) was tested, but confusion between spectral signatures of land types made it impossible at this level and quite broad class groups were used.

Using the final training set, the complete satellite image was classified (Figure 6). This result was subjectively evaluated on a land district basis by comparison with the ecological base map, detailed aerial photographs, and ground sampling. Figure 6 demonstrates the differences and relationships between the unclassified images, automated classification and visual interpretation.

Table 5 shows the results of this evaluation. The ratings only identify the classification accuracy of the different classes in the training set. Whether the particular class itself is satisfactory from an ecological viewpoint is not considered. Table 5 shows that the overall performance of the classifier is satisfactory. Best results (70%) are achieved in the Mack Lake, Knife Rivers and Seal River districts, possibly because these districts have seven or fewer classes. The Lofthouse-Lake district and its transition zones perform uniformly with about 65% classification accuracy. The Coastal Zone has the poorest showing: none of the classes except 'water' and 'willow/alder/birch' perform well.

DIVERGENCE MATRIX

CLASS

	1	2	3	4	5	6	7	8	9
1	0.00								
2	15.78	0.00							
3	29.71	80.78	0.00						
4	69.29	24.64	105.96	0.00					
5	255.62	343.49	305.87	776.03	0.00				
6	51.28	77.46	30.56	130.40	612.99	0.00			
7	64.68	90.33	45.13	160.84	809.39	18.54	0.00		
8	54.83	130.89	32.09	267.86	531.33	8.68	37.20	0.00	
9	6.56	42.06	17.60	122.87	311.42	32.30	33.39	38.17	0.00

CONFUSION MATRIX

True Class

Chosen Class	1	2	3	4	5	6	7	8	9
0	0	0	0	0	0	0	0	1	0
1	89	3	0	0	0	0	0	0	10
2	1	96	0	0	0	0	0	0	0
3	0	0	94	0	0	0	0	5	2
4	0	1	0	100	0	0	0	0	0
5	0	0	0	0	100	0	0	0	0
6	0	0	0	0	0	89	5	5	0
7	0	0	0	0	0	3	95	2	1
8	0	0	1	0	0	8	0	86	0
9	10	0	5	0	0	0	0	1	87

MEAN SPECTRAL INTENSITIES

Class	Band	4	5	6	7
1 - sedge-bs/th		15.4	13.0	19.6	11.7
2 - open black spruce		14.8	11.1	21.9	12.9
3 - stonefields		18.3	16.2	21.1	11.1
4 - willow - alder-birch		14.9	10.5	27.5	18.3
5 - water		13.2	9.2	7.1	0.9
6 - peat plateaus		19.1	18.4	27.9	17.7
7 - peat polygons		17.5	17.4	25.7	17.3
8 - lichen/sand-till		20.5	19.5	27.7	16.8
9 - patterned fens		16.7	14.7	21.2	12.6

Table 4: Divergence and Confusion matrix and means statistics for the 'final' training set.

Although the classification results can be described as satisfactory for the total map area, they do not indicate that the automated classification can generate useful results. The nine-class final legend is too broad and too sinple to be of much value. As a vegetation classification, the results could be considered successful; however, as a biophysical classification, the method performs poorly. As there is a relation between classification results of land districts and distribution of classes, automated classification may be improved by classifying on a land district basis. This procedure implies that training takes place within a district and is repeated for each district, and that legends

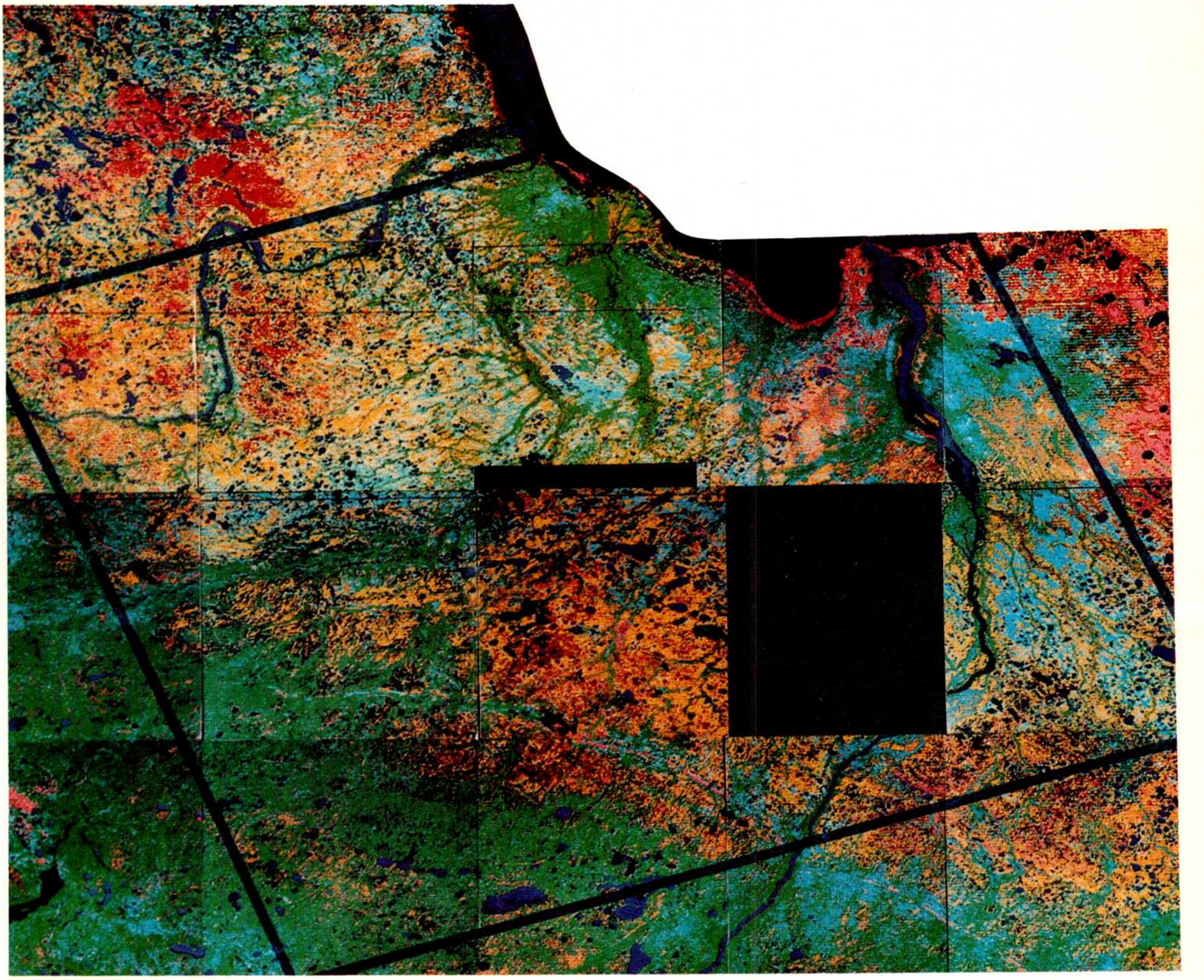


Figure 6: Map III - A supervised automated classification of the Churchill area. Map-sheet 54L is identified by thick line. Colour themes were generated through the use of the CCRS Multispectral Analyser Display (MAD).

dark blue - water
light blue - sedge-bs/tl
green - open spruce
red - stone fields
orange - willow-alder

brown - peat plateaus
yellow - peat polygons
pink - lichen/sand-till
grey - patterned fens
black - unclassified.

*Table 5: Evaluation of supervised automated classification results for total map-area and for each land district: 1 - very poor; 2 - poor; 3 - imperfect; 4 - satisfactory; 5 - good; and 6 - very good. *Indicates that the particular class does not occur in appreciable quantity.*

CLASS	KNIFE RIVERS DISTRICT (2B)	MACK LAKE DISTR. (2A)	SEAL RIVER DISTR. 1A	LOFTHOUSE-LOVETT LAKES DISTR			COASTAL DISTR. 1C	TOTAL MAPSHEET
				TRANSITION 1B-2B	1B	TRANSITION 1B-1C		
1 Sedge-bs-tl	1	3	2	3	2	3	1	3-
2 Open black spruce	4*	5	4-	4-	4-	3	3	4-
3 Stonefields	5*	6*	4+	5*	6*	5*	4*	4+
4 Willow/ald/birch	6*	6*	6*	6*	6*	6*	4+	4+
5 Water	5	5	6	5	5	5	5	5+
6 Peat plateaus	4	4+	5*	4	3-4	4+	1	4
7 Peat polygones	5*	2	4	3	4	2-3	2	4-
8 Lichen-sand-till	4-	4	4+	4-	3	2	3	3+
9 Patterned fens	6*	6*	2	3	2	3	1	3-
10 Unclassified	5	3	5	2	3	5	4	4
All Classes	4	4+	4	4	4	4	2	4

would vary according to districts. Confusion would be reduced considerably. However, it would also increase the reuired time for training and classification of a satellite frame 5 to 20 times, assuming that about 5 to 20 land districts are likely to occur in one satellite frame. Although this procedure would not drastically increase computer time, it would require a number of days of interactive supervised training, with the probable result of a 20- or fewer class legend, varying according to land district and heavily biased toward vegetation.

Unsupervised Automated Classification

In the three test areas (Seal River, Mack Lake and Lovett Lake), supervised classification was carried out using a multidimensional histogram approach (Goldberg and Shlien, 1975). In this method, the image to be classified is scanned and a four-dimensional histogram of intensity vectors is created. By choosing a threshold, the intensity vectors can be grouped into clusters. The interpreter chooses the threshold value. This procedure makes the approach interactive; the interpreter can break up a specific cluster by raising the threshold value and treating only the vectors belonging to that cluster (Goldberg and Shlien, 1975). Figure 7, showing the Long Island area and part of the Lovett Lake test area, permits the comparison of an unsupervised clustering (A), a supervised classification (B), and interpretation (C) of 1:100,000 scale black and white photographs. (C) shows typical biophysical land systems as complexes of land types, with each primary land type identified by a class and percentage of occurrence. The unsupervised classification provides the most detailed map themes. (A) is the result of about 16 clusters, only 10 of which occur in considerable quantity. (B) maps only 9 class groups.

The unsupervised clusters are not better classes or land types than the ones derived from supervised classification. In fact, the results of the supervised classification closer to an ecologically desirable map than are the results of the unsupervised classification.

The advantage then of the unsupervised technique is that the computer, with little user interaction and time, gives an impression of which objects are separable. However, relating clusters of practical classes and themes and grouping them is usually not a simple task. It can be time-consuming and still not provide the most desirable classification. In addition, such 'editing' requires at least as much ground control as is needed for supervised classification.

Use of Multidate Imagery for Automated Classification

The visual interpretation of satellite images has demonstrated the value of using multidate satellite imagery for classification purposes (Thie *et al.*, 1974; see Figure 8). Kalensky (1974) also reported improved classification accuracy for vegetation mapping using multidate information. Winter imagery, especially, contains information that is complementary to summer date. Figure 9 demonstrates the considerable difference between the spectral characteristics of a summer and a winter channel As a result of the very special associations among vegetation, soils and permafrost in this subarctic area, winter imagery enhances, for example, the distribution of well-drained glaciofluvial and beach deposits. The Seal River test area was used for the multidate evaluation as it has suitable representation of mineral and organic soils, and vegetation is not visibly disturbed. Both supervised and unsupervised classifications were applied to a tape composed of three summer channels and one winter channel. The addition of the snow covered image was mainly beneficial for areas covered with vegetation (trees and shrubs) that is sufficiently high enough to penetrate the snow layer and dense enough to lower reflectance values of

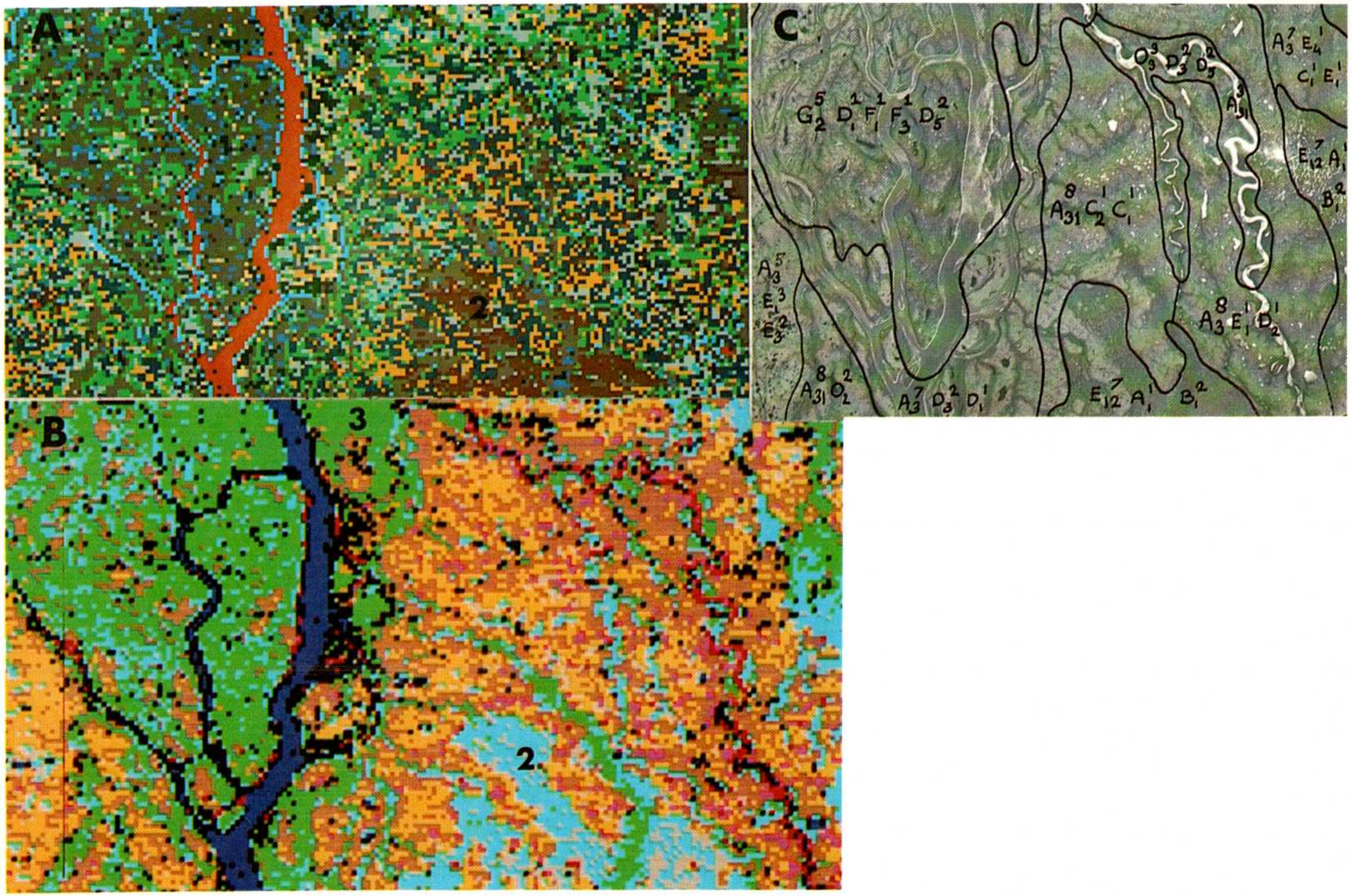
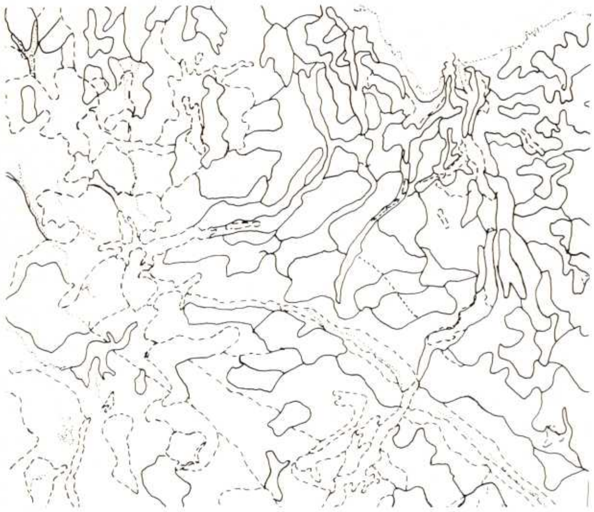


Figure 7: Comparison of unsupervised A, *supervised* B *and interpretation of B&W aerial photographs. Colour scheme of* A *is explained in Figure 4.* C *shows land system with percentage of land types.*

Figure 8: Land system boundaries derived from summer (closed lines) and winter (broken lines) satellite imagery through visual interpretation.



snow. However, in areas either devoid of vegetation or with the vegetation completely covered by a snow mantle, the addition of the winter channel was not beneficial, and occasionally lowered classification accuracy. Such was the case with the stone field theme.

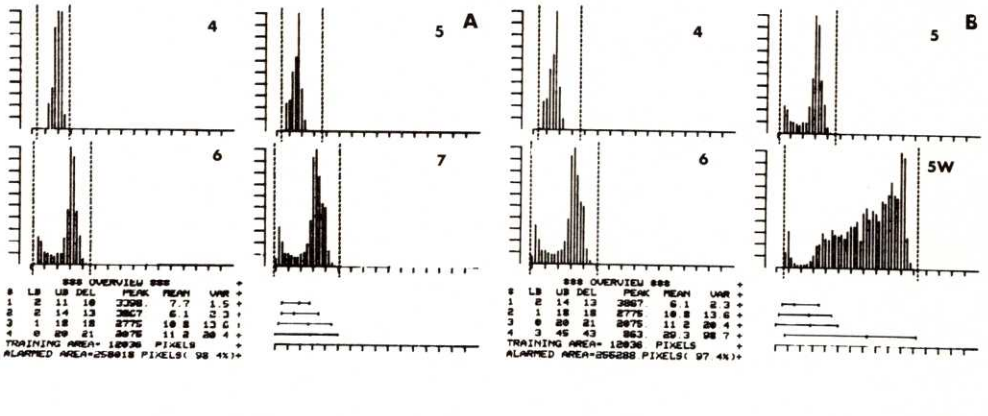
COMPARISON OF INTERPRETATIVE METHODS — DISCUSSION

Table 6 compares the time and cost requirements for the various interpretative methods, including those for the ecological base map. In addition, the information value of each of the maps for resource management was subjectively estimated, based on the requirements for *regional* resource planning. Out of a possible value of 100 (i.e. satisfying most biophysical information requirements for regional resource planning though not necessarily local requirements), the satellite-based techniques do not score higher than about 15 (1:250,000 visual satellite interpretation). The ecological base map, made through conventional photo-interpretation, has a value of about 75.

Taking into account the time and cost considerations, Table 6 shows that visual interpretation of 1:1,000,000 LANDSAT imagery is the most cost-effective satellite interpretation method.

Of the 50 representative land types for the area, only a few can be mapped satisfactorily using the satellite techniques. This means that spectral signatures are inadequate to map land types using automated techniques and that the addition of shape information using visual techniques does not change this significantly. The success of the photo-interpretation in mapping and describing 43 of the 50 land types is likely the result of the relief information available in the three-dimensional model, and the shape information of landforms and micro-landforms, rather than signatures.

To obtain a reasonable classification with the tested interpretative methods, the 50 land types (classes) had to be joined into broader class groups. In this way, 15 class groups were separable with the visual satellite interpretation and about 10 with the automated techniques. These class groups are so broad



```
          $$$ OVERVIEW $$$            +
#  LB  UB DEL    PEAK   MEAN    VAR +
1   2  11  10    3398.   7.7    1.5 +
2   2  14  13    3867    6.1    2.3 +
3   1  18  18    2775   10.8   13.6 +
4   0  20  21    2075   11.2   20.4 +
TRAINING AREA= 12036  PIXELS        +
ALARMED AREA=258018 PIXELS( 98.4%)+
```

```
          $$$ OVERVIEW $$$            +
#  LB  UB DEL    PEAK   MEAN    VAR +
1   2  14  13    3867.   6.1    2.3 +
2   1  18  18    2775.  10.8   13.6 +
3   0  20  21    2075.  11.2   20.4 +
4   3  45  43     863.  29.3   98.7 +
TRAINING AREA= 12036. PIXELS        +
ALARMED AREA=256288 PIXELS( 97.4%)+
```

Figure 9: One-dimensional histogram displays of the intensities of the composite summer-winter image B (summer channels 4, 5 and 6; winter channel 5W) and the summer image A (summer channels 4, 5, 6 and 7) for the same clustering training area. The horizontal axis displays the reflectance values (from 1-63) and the vertical axis, the frequency of pixels with those values. Note the wide range of distribution and the skew towards light reflectance values of (5W).

Table 6: Time and Cost Considerations

TIME AND COST CONSIDERATIONS*

Per 13,000 Km^2

		Time	Mat.	Labor	Information Value
1:1,000,000	LANDSAT (VISUAL)	15-20 hrs	$ 100	$ 600	8-10
1:250,000	LANDSAT (VISUAL)	80-100 hrs	$ 100	$3000	15
AUTOMATED	LANDSAT	15-20 hrs	$2000	$ 600	5-10
1:100,000	Ecological Base Map	120-160 hrs	$ 200	$4800	75

* Only listed is the time and cost for interpretation of imagery. Cost of fieldwork is not included. Fieldwork cost can be considered the same for all methods. It constitutes up to 80% of the total survey cost for conventional type surveys, depending on the accessibility of the area. (Thie et al, 1974).

that their value to resource managers is very restricted, hence the low rating (5-15) in Table 6. The study indicates that an increase in the physiographic or ecological complexity of the land area causes an increase in misclassification with all satellite interpretative techniques. The more complex areas have a greater variety of surficial materials, vegetation and relief. The present resolution as well as the lack of detailed relief information appears to be the main limiting factor to apply satellite interpretative methods.

This study demonstrates that classification methods based only on spectral signatures did not map enough land types. The relative success of the visual analysis as compared with automated methods might be due to the use of shapes and spatial patterns in the interpretative process, as well as the use of multidate images. This apparently more than compensates for the loss in spectral information. It can be argued that present automated interpretative techniques allow geometric corrections, multidate overlays, and simple spatial feature analysis. While they should improve classification results, they also require additional computer and training time. Costs involved *at present* make it unattractive for operational use.

This study was unusually simple for Canadian circumstances with regards to ecology and physiography. The land surface is flat or at most lightly sloping. Surficial materials cover extensive areas and are not mixed. Most important, due to a lack of distrubing agents, vegetation and therefore its signatures can be considered a good indicator of ecosystem or land type conditions. Thus, changes in relief, soil, drainage, landform, habitat, etc. are reflected in vegetation gradients or boundaries. However, this exceptional situation does not hold for most of Canada. Vegetation has been disturbed through land use, and in northern areas, forest fires and disease are even more important. In those situations, changes in vegetative cover are not usually related to changes in land types. Figure 10 gives a striking example of the impact of forest fires on the vegetation pattern of the boreal zone in Canada. Satellite imagery classification, expecially automated performance, can be expected to drop considerably in such areas. While mapping of vegetative cover type can be reasonably successful with digital techniques, soil, landform, and land type classifications appear doomed to fail for large areas, except large wetlands.

The above mentioned limitations do not apply to air photo interpretation techniques. Through the use of relief and shape information, fire boundaries can be identified, and only those vegetation boundaries are used that are considered to reflect land type conditions.

CONCLUSIONS

Taking into consideration the usefulness of data resulting from the various interpretative methods for resource management purposes, photo-interpretation of small scale aerial photographs *presently* provide the best cost- and data-effective method for ecological land classification in Canada. Satellite data should be used in a complementary way; that is, to assess and delineate environmental dynamic phenomena,

Figure 10: Forest fire patterns in the boreal zone near Black Lake, Saskatchewan. The snow cover on this 7 March, 1974 LANDSAT image enhances the complex forest fire pattern. Some areas (A) *were burned more than 100 years ago, others very recently* (B)*; most of the area is burned repeatedly. This image shows forest fires to be an integral part of the boreal ecosystem.*

and to delineate land districts.

Visual interpretation of 1:1,000,000 multidate satellite imagery provides an operational alternative only if more than 20,000 km^2 per man-year has to be mapped, and then only in ecologically and physiographically simple areas: arctic, subarctic, and large wetlands in the boreal zone. Automated classification appears, *at present,* unsuitable for ecological land classification in Canada. While certain simple maps can be made for arctic and subarctic areas and boreal wetlands, the practical usefulness of this information is somewhat in doubt. It is expected that this assessment will change when a significant breakthrough occurs in the automated analysis of shapes and textures.

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