CANADA'S NORTHLANDS

Ecological Land Classification Series, No. 0

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M.J. Romaine and G.R. Ironside

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REMOTE SENSING FOR NORTHERN SURVEYS AND ENVIRONMENTAL MONITORING[1]

Jean Thie
Canada Centre for Remote Sensing
Department of Energy, Mines and Resources
Ottawa, Ontario

INTRODUCTION

Classification systems for mapping and describing the earth's surface evolved from single discipline oriented systems into integrated ones — from separate soil classifications, vegetation classifications, forest inventories and geomorphological systems, into ecologically based ones. In brief, an adequate survey system should:

1) be ecologically based
2) integrate water and land classification
3) describe present status
4) allow for monitoring of changes (natural or man-caused)
5) map and describe units for multidisciplinary resource planning and/or management
6) be rapid and inexpensive

Under the auspices of the National Committee on Forest Land, the development of a biophysical classification system for Canada was started. The aim was to differentiate and classify rapidly at a small scale ecologically significant segments of the land surface (Subcom. on Bio-phys. Land Class., 1969). It was recognized from the start that such a system should be ecologically based — mapping and describing land surfaces in such a way that judgments related to forestry, wildlife, waterfowl, recreation and agricultural (if applicable) potential could be made with little additional effort. The levels of classification proposed — land region, land district, land system and land type — appear adequate and flexible for most resource planning and management requirements as well as for impact prediction. One weakness of the system, however, is that it is a land-oriented classification system, and does not consider the integration of land and water. Water is an important resource in the North, from a recreational, fishing and wildlife point of view. A northern survey should pay proper attention to this aspect and integrate land and water classifications into manageable units. Also, while the biophysical system, because of its ecological basis, recognizes environmental changes and describes succession, more attention should be directed to present conditions and man-caused or natural changes.

The development of new remote sensors has added new dimensions to the survey of the environment. Multiband sensor packages aboard aircraft and satellite allow us to measure or map 'new' parameters such as surface temperatures, thickness of ice, air pollutants, etc., as well as enable us to better discriminate objects of interest. Repetitive remote sensing adds a time dimension to the survey, and the LANDSAT satellite, orbiting Canada four times daily and covering each part repetitively with an 18-day interval, can play a significant role in realizing an environment survey system that will be truly ecologically based, integrating land, water, atmospheric and biological phenomena as well as the interaction with living organisms including man. It is my intention to analyse and illustrate the operational and potential significance of remote sensing to northern resource data gathering.

AIRBORNE REMOTE SENSING

Interpretation of aerial photographs has been a common practice for most operational surveys (eg soils, landforms, forestry, crops, land use, etc). In the field of land classification, the photo interpretational inference techniques and extrapolations from selective field sampling have proven quite successful. In the Manitoba biophysical pilot project, an area of about 14,000 km^2 was mapped and described in less than 1 man-year (Zoltai *et al.*, 1970). The work was done by the interpretation of black-and-white photographs at a scale of about 1:63,000.

The important information stored on an image, and used for classification, is relief, shape, tone and texture (or 'signature'). Relief and

[1] Technical Paper 74-13, Canada Centre for Remote Sensing.

shape especially contain valuable information for inferring conditions which cannot be 'seen' directly; tone and texture help to differentiate between objects. Airborne remote sensing adds little if anything to the relief and shape information. Its main value lies in increasing the contrast of surface features — it may make certain parameters visible which we cannot see with our eyes or by conventional photography. For example, infrared photography helps to detect stress symptoms in plants (disease, moisture, etc.) and generally provides very good discrimination between vegetation types. Different studies have indicated that 1:120,000 scale colour infrared imagery can provide the equivalent amount of information as 1:60,000 black and white (Thie, 1971). This smaller scale can reduce mapping most for interpretation, while the more synoptic view (about 640 km^2) provides a superior base for land system and district analysis. Multiband photography can be valuable for land and water classification systems. It would enable the simultaneous use of water penetration film (colour or blue-green) and land-vegetation film filter combinations (colour or colour IR with different filters).

Multi-spectral scanners on board aircraft may be of some use in the future. Their theoretical advantage is that they can measure the radiation in a very narrow 'band' of the electromagnetic spectrum and can therefore optimize the spectral reflectance differences between objects. Computer handling and interpretation of data is presently quite costly, so much so that instruments of this nature are of little operational interest. Single-channel or dual-channel scanners, especially in the thermal infrared of the spectrum, however, seem advantageous to include in a sensor package. It allows mapping of temperatures to about 0.5°C during the day and night. Repetitive flights with such instruments can be used to describe and measure the temperature regime of land types over time (eg frost pockets or exposure influence) and help approximate microclimate over large areas at low cost. It can also be used for the detection of ground water discharge areas, incipient forest fires, water pollution, or lake surface temperatures.

The value of side-looking radar imagery for land classification purposes is still uncertain. Experience with it in Manitoba (Thie, 1974) showed little promise for mapping land systems, although cultural features such as farm fields and buildings, transmission lines, etc. could be successfully mapped. A number of new sensors are being developed, such as the HISS radar (Holographic Ice Surveying System) and soil moisture meter. If successful, these systems will be able to add important quantitative data. Laser fluorosensors, presently under development, will be useful for bathymetric surveys in shallow water areas, for fish tracking, and for monitoring oil slicks and dyes on water. LIDAR, optical probing of the atmosphere with a high-power laser source, may add significantly to a limnological or atmospheric survey (MacDowall and Lapp, 1973).

SATELLITE REMOTE SENSING

Satellites, such as the earth observation satellites (LANDSAT - previously ERTS) and some weather satellites (eg NOAA) should be considered for use in the north. Both can be received directly by the Canadian Receiving Station in Prince Albert, Saskatchewan. The characteristic difference between the two types is in scale, resolution, and frequency of orbit. LANDSAT satellites have a 4-channel multispectral scanner which registers in the Green, Red and two near-infrared bands of the spectrum. The NOAA satellite provides, in addition to this, thermal 1R scanning.

Scale and Resolution

The scale of imagery produced from LANDSAT is 1:1,000,000. Photographic enlargements to 1:250,000 and even 1:125,000 provide high quality imagery for interpretation and mapping. The biophysical land classification system suggests the following mapping scales for its levels:

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 resolution and scale of LANDSAT seems suitable for mapping at the first three levels. Considering that on the computer compatible tapes from LANDSAT the minimum resolution of 1 pixel represents 76.2 m x 76.2 m on the ground, even some use for land type mapping can be expected. In the Churchill and Mackenzie areas (Tarnocai and Thie, 1974), LANDSAT provided very detailed information from computer tapes, and the major problem encountered was in reducing this amount of data into significant larger complexed units. This can be done by using human or automated interpretation techniques. At present the human based ones are more effective, certainly for biophysical type of classifications. The scale of the NOAA imagery is extremely small; one picture covers about half of Canada. Although the resolution is much poorer than LANDSAT, high contrast phenomena can be monitored effectively (eg snow and ice, large burn areas in winter).

Repeated Coverage

The NOAA satellites cover Canada every day, and LANDSAT has an 18-day interval between passes over the same area. For the high north, successive coverage up to five days can occur. Repeated imaging of the same area throughout the growing season, through winter and over a number of years will help access and define the dynamics of our environment. This is an aspect which has been missing even in most ecologically based surveys, though vegetation succession may have been described. Seasonal imaging will help in relating phenological phenomena, disease development, moisture stress symptoms, snowmelt, and ice movements to other physiographic parameters such as landforms, soil, relief, exposure, water, etc. Winter images can enhance particular surface phenomena such as snow cover, and low sun angles enhance relief and fracture interpretation. Winter imagery in the Moose Lake area in Manitoba showed a good discrimination between black spruce and jack pine vegetation types. These are difficult to separate on summer images and even on conventional black and white photography with a scale of 1:63,000. The time of the year changes the spectral response from the vegetation associations; with conifers this may be largely due to the changes that take place in the reflection of vegetation substrata and ground cover. Another easy application is monitoring the freezing of water bodies and river systems. Even in mid-winter, parts of northern rivers (eg the Churchill River) and northern lakes (eg South Indian Lake) show open water leads. These may have significance from the wildlife point of view, and certainly do for fish considerations.

Changes that occur on the surface of the earth can be monitored from satellite gross way — eg natural phenomena such as forest fires (frequency of occurrence, areas burned, habitat destroyed), regeneration in disturbance areas, fluctuations in surface moisture (saturation of wetlands, flooding, etc.) and changes in waterbodies (freezing, thawing, fluctuation in water levels and size, turbidity, and suspended sediments). Such information should be very valuable in approximating the dynamic aspects of the ecological building blocks.

Monitoring of man-caused changes could add significantly to sensitivity ratings of 'Land types' to such changes. Satellite has shown examples of SO_2 damage, shoreline erosion and increased turbidity as a result of artificially higher water levels in lakes, the effect of logging activities on waterbodies, road construction and drainage, dredge spills, urban expansion, and other land use changes.

A combination of NOAA and LANDSAT satellite monitoring is specially attractive for fast change high contrast phenomena such as snowmelt, ice reconnaissance, and surface temperature patterns. The daily coverage by NOAA complements the less frequent, high-resolution LANDSAT. The NOAA imagery may also be of much value for defining the biophysical land regions. These regions are defined by a distinctive regional climate as expressed by vegetation. The temperature information and the extremely small scale of this satellite may add regional climatic parameters.

LAND/WATER INTERFACE

The synoptic view from satellite has clearly shown the relationships between physiography of the 'land' area and water signatures. A very strong relation is apparent between lake and shoreline shape, water reflectance (in the green and red bands) and the surrounding land areas. This relationship is often so strong that water information can be used to infer parent materials and shoreline conditions from turbidity information and lake shapes. In fact, based only on lakes (providing a fairly large number occur in a map sheet), a general physiographic map can be drawn for many areas. Landscape units or even land systems that are uniform as to physiography could often be subdivided based on spectral reflectance of water.

The more sensitive areas of South Indian Lake in Manitoba can be readily identified from satellite, and this is not merely a confirmation of what was known, but a significant addition to the data base which, without the satellite, would have gone unnoticed.

Regional limnology and regional lake surveys can especially benefit from satellite. The satellite will also enable future survey teams to integrate land and water classifications as they will integrate wetland and upland systems.

LAND CLASSIFICATION

As previously mentioned, the LANDSAT scale and resolution are suitable for reconnaissance type of surveys. Work with LANDSAT in Northern Manitoba showed that satellite can be a very effective mapping tool, especially for arctic and sub-arctic areas. Most land systems at a

1:250,000 scale (even at a 1:125,000 scale) can be readily drawn from satellite images. This is also the case for large (organic) wetland areas in the boreal zone. Vegetation in both cases is a good indication of ecosystems, as relatively few disturbances (fires) that distract from these have occurred. In the boreal zone, with its forest cover, broken precambrian physiography (in Manitoba, that is) and its complex fire history, mapping from LANDSAT cannot be as easily achieved. Land systems delineation by means of visual techniques is more complicated and the results are less accurate. Combinations of winter and summer images must usually be used to increase accuracy. No significant work with automated classification has been done yet. It is too early to say that these could improve classification considerably. The land/water relations discussed before were conspicuous in parts of the boreal zone and could be successfully used as a source for land/water delineation. Satellite can recognize significant changes in the distribution of parent materials, when these are expressed by vegetation. Land systems that may differ by less than 20% in the distribution of surface materials may be difficult to separate from a satellite image in the strongly broken precambrian areas.

While satellite imagery can assist im mapping of significantly different land systems, the description of the land systems will have to be based on a description of the land types (ecosystems). For the analysis and description of these 'building blocks', airphoto interpretation is essential and cannot be replaced (airborne sensing could be used to provide additional data).

HUMAN VERSUS AUTOMATED INTERPRETATION TECHNIQUES

Human interpretation techniques are superior for the analysis of airborne as well as satellite Remote Sensing Data for biophysical land classification. Automated interpretation is still in its childhood, and is not expected to produce methodology that will eliminate a human interface within the next five years. However, computer compatible tapes from satellite store considerably more information than black-and-white or colour images produced from them. For instance, the 64 'density levels' of the tape can only be translated into 10-12 grey tones on a black-and-white hardcopy or transparency for the same band. Effective use of all this information will require a computer at some stage. In addition to 'signature' however, shape is critical for delineation and identification. Thus, much of this disadvantage is compensated for as there are no automated techniques yet that can adequately analyse shape. Again, *in relatively simple areas* such as the Hudson Bay lowlands, *automated classification can be very successful.*

Human interpretation can be aided by special enhancement type of equipment such as a colour additive viewer, colour density slicers, or even simple diazo and agfacontour slicing techniques. While these instruments and techniques have their place, their value should not be overemphasized. Some of them (colour additive viewer, agfacontour and diazo) allow temporal overlays of satellite imagery that can be attractive for time-change studies.

In summary, I feel that human interpretation of aerial photographs will always form the most essential component of rapid biophysical surveys.

Cost Considerations

The Airborne Remote Sensing Unit of the Canada Centre presently provides multiband sensing for experimental and development projects on a subsidized price. For 1974, the charge was about \$3.40 per sensor line km; there will also be charges for development of film, printing, etc. On a commerical basis, the price would be closer to the \$25.00 per sensor line km, depending on sensor package, location, size of area, etc. In an operational project, this would mean about \$20.00 for a high-altitude super-wide angle coverage, including some lower level flights for an area of 1,800 km^2.

All of northern Canada is presently covered by black and white 1:63,000 scale photography. Although reflying complete mapsheets is financially unattractive, it would be very effective to fly selected parts (selected by means of satellite) with airborne remote sensing, possibly on a repetitive basis. This would reduce the cost by at least 75%. The combination of satellite, old black-and-white, small scale photography, and recent airborne multiband remote sensing is an attractive low-cost package. The charges for satellite imagery are minimal.

Most of the costs involved in a northern survey are for fieldwork and mapping purposes, and it is therefore unlikely that the use of satellite and airborne remote sensing will reduce cost by more than 25%, if at all. However, the end result, the description and approximation of ecosystems could be significantly improved.

The Manitoba pilot project indicatd that an acceptable mapping can be produced for about $43,000 (Goulden and Thie, 1970).

The use of satellite remote sensing in combination with selective airborne sensing could be quite powerful if somewhat different approaches are taken. A rapid general type of mapping, using LANDSAT, selected airphoto interpretation and selected field work as main tools, could likely be completed for about $10,000-20,000 per mapsheet. A more detailed regular type of biophysical mapping in areas of high priority could require the regular $40,000 or more if desired in special circumstances (impact studies, etc.) Taking Manitoba as an example, for about $500,000, an area of about 420,000 km^2 could be surveyed in about 3-4 years time.

AN OPERATIONAL SYSTEM

Satellite imagery can provide a basic operational tool for a rapid resource survey in combination with existing black-and-white photography and supported by selected airborne sensing. Based on experiences with satellite data, the following procedure is suggested:

1) The formation of a team composed of one ecologist, one pedologist-geomorphologist and one limnologist. The ecologist should have a wildlife background, otherwise a wildlife biologist may have to be added to the team.
2) Existing satellite data should be used to delineate (preliminary) land districts and broad land systems (1:250,000 scale). Repetitive imagery and enhancement techniques should be used.
3) Based on satellite, areas should be selected for airborne sensing, photo interpretation and field work.
4) Based on fieldwork selected areas (land types) should be described. Based on temporal satellite data, dynamic phenomena should be included.
5) Results extrapolated using satellite where possible.
6) Final maps to be prepared on LANDSAT mosaics.
7) Total cost about $10,000-20,000 per 12,800 km^2.
8) A detailed survey can be carried out simultaneously in high priority areas. This survey will have to be mainly based on airphoto interpretation. LANDSAT's role is strongly reduced (relatively speaking).
9) Continuous updating of conditions using LANDSAT, as well as monitoring effect of management and planning decisions.

Points 1-6 could be completed in a period of 3-4 years; 8 would require significantly more time (10-20 years), while 9 would be done continuously in areas of rapid change.

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DISCUSSION ON THE PRESENTATION

G. Beanlands inquired about the potential for LANDSAT in climatic mapping. *Thie* felt that there were severe limitations. With NOAA (weather satellite) and LANDSAT he felt that there were some possibilities for use. He indicated that he had done no work on weather or climate studies. *G. McKay* felt that there was some potential for use of LANDSAT in this regard. He indicated that NOAA has been used in this respect, and there is also potential in this area for high resolution satellites.