AIRCRAFT AND SATELLITE REMOTE SENSING FOR BIOPHYSICAL ANALYSIS AT PEN ISLAND, NORTHWESTERN ONTARIO

AIRCRAFT AND SATELLITE REMOTE SENSING
FOR BIOPHYSICAL ANALYSIS
AT PEN ISLAND, NORTHWESTERN ONTARIO

by

NANCY JEAN KOZLOVIC

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AUTHOR: Nancy Jean Kozlovic

SUPERVISOR: Dr. P. J. Howarth

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ABSTRACT

The capabilities of a number of remote-sensing techniques for biophysical mapping in the subarctic have been examined at Pen Island in northwestern Ontario. After a two week field reconnaissance, colour infrared aerial photography was studied and a detailed biophysical map of the area was produced. Using this knowledge LANDSAT satellite data of the site were investigated. In a visual analysis of the data, the majority of the units identified in the airphoto interpretation were detected, and these were distinguished primarily by their spectral characteristics. Digital analysis of the satellite data using the Bendix MAD system allowed many of the classes of the earlier studies to be delineated and also permitted the classification to be readily extended beyond the original site. In both LANDSAT analyses specific biophysical units could be mapped from the satellite data but could not be identified without the airphoto interpretation.

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CHAPTER I

INTRODUCTION

1.1 Purpose of the Study

The subarctic environment of northern Canada is an extensive and relatively unknown landscape that lies north of the boreal forests but south of the Arctic tundra. A transitional zone between the two, it is characterized by close relationships among its various biological and physical attributes, especially among the vegetation, soils, geomorphology and drainage. With increasing exploration and exploitation of the natural resources of the North, there is an urgent need for a better understanding of this ecological system in order that proposals for development may be carefully evaluated and do the least harm possible to the human and natural components of the region.

Field investigations are an important source of information in any environmental study, but when the area is widespread and remote, they become very costly in terms of time and money. In much of the subarctic, they are also very difficult due to the abundance of surface water and peatland formations. The problems of expense and inaccessability for field investigations have created a heavy reliance upon aerial surveys in the regional analysis of subarctic Canada. Panchromatic photography in particular has been employed, but in recent years technological advances have made available a number of other types of photography, as well as satellite data.

Since the various natural aspects of the subarctic environment are interrelated, mapping in this region should adopt an integrated or biophysical approach. Aerial photography and other means of remote sensing are an ideal source of this type of information, as they show the nature of and the spatial relationships among many of these parameters. Yet many of the currently available methods have rarely been applied. In light of this situation, the present investigation evaluates the suitability of some of the more recent techniques of remote sensing for biophysical mapping in the subarctic. Using field studies as a source of detailed background knowledge, it examines the information content of colour infrared aerial photography and LANDSAT satellite data by a number of different methods of analysis.

1.2 Area of Study

The site selected for this investigation is located on the southern coast of Hudson Bay in extreme northwestern Ontario (Figure 1.1). It lies opposite East Pen Island, a barrier island separated from the mainland by a deep, narrow channel. Although the study is concerned with the mainland,the site is referred to as "Pen Island" as this is the only distinctive feature in the area.

The Pen Island site, which is underlain by continuous permafrost and rests atop flat-lying Paleozoic limestone, is characterized by very low relief, widespread organic terrain and extensive standing water. It has been undergoing isostatic recovery since its time of deglaciation, about 7,300 years ago (Craig, 1969). Originally the area was completely submerged, but it is currently emerging from the sea at

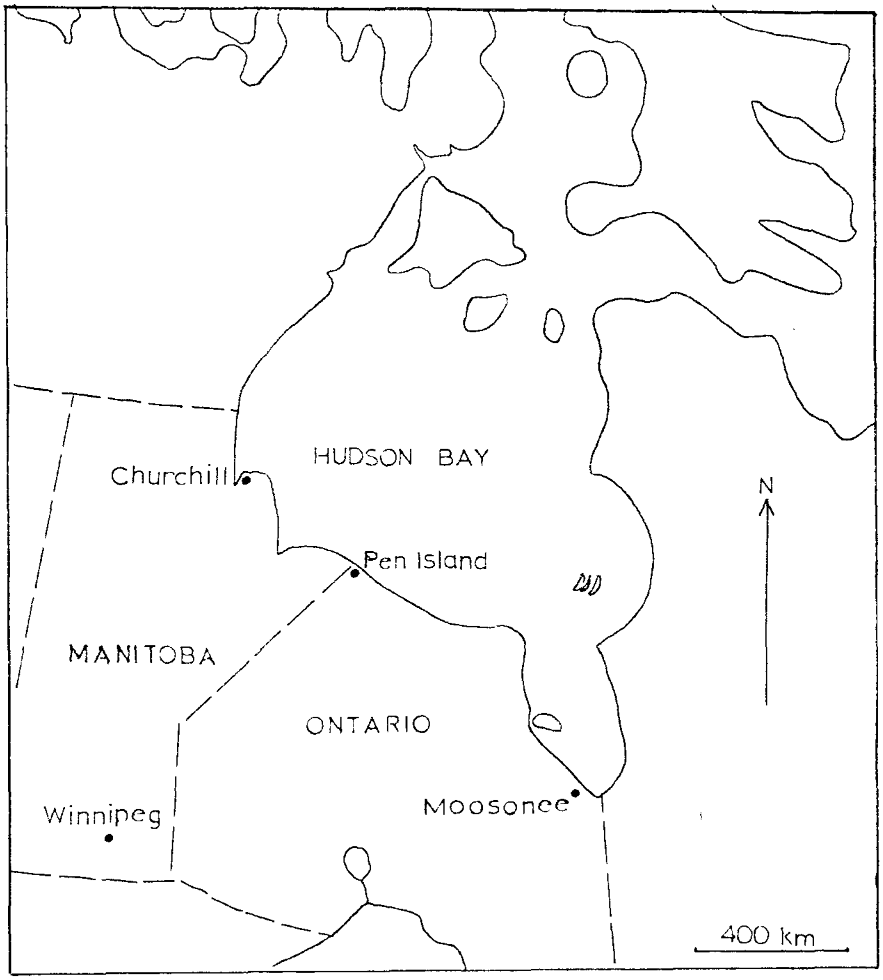


Figure 1.1 The location of Pen Island

an estimated rate of 0.7 to 0.8 metres per century (Andrews, 1970). This continued uplift has produced a long series of relic or fossil beach ridges, which extend about 280 km inland from the coast at Pen Island (Lee, 1968). The ridges have developed into upland environments that are markedly different from the surrounding wetlands.

With its continuing isostatic recovery and position on the southern shore of Hudson Bay, the Pen Island site exhibits two major geographic regions oriented parallel to the coast. One is the "hemi-arctic" (Sjors, 1961), a treeless area whose vegetation approaches that of the true tundra. Located immediately adjacent to the coast, this is a young landscape that is directly exposed to the strong and frequent onshore storms. The other is the partially wooded subarctic. With its inland position of at least 9 km from the shoreline, this landscape is older and less exposed than the coastal zone, and is therefore capable of supporting tree growth in certain locations. For the purposes of this thesis, both landscapes are considered to be subarctic environments.

Selection of the Pen Island district for this analysis of remote sensing data is based upon two important factors. First, it has been the object of intensive field investigations for a number of years by microclimatologists and plant ecologists at McMaster University. The information generated by these ground studies is a valuable input to a programme of biophysical mapping. Second, the Pen Island site is representative of much of the southern shoreline of Hudson Bay from Churchill in the west to James Bay in the east. The results may, therefore, be useful to future studies almost anywhere along the coast.

1.3 Data Sources

The information required to carry out the analysis of the landscape at Pen Island is of two types; namely, field data and remote sensing.

The field data were gathered in late August and early September in conjunction with an undergraduate field course in plant ecology. The site was reached by aircraft, and ground investigations were carried out on foot. They involved an examination of various aspects of the subarctic environment at Pen Island during the two-week stay at the site.

The remote sensing data were obtained through the Canada Centre for Remote Sensing (CCRS) in Ottawa. These include aerial photography and satellite data. Details are presented for each in Table 1.I.

The aerial photography was flown on July 23, 1973 through CCRS Task Number 73-40. It was obtained by means of a Wild RC-10 Camera equipped with a superwide-angle lens of focal length 86.4 mm.

Kodak Infrared Aero film,Type 2443,was used,along with a Wratten Number 15 deep yellow haze filter and a 3.3 times antivignetting filter. The aircraft flew at an altitude of 6100 m above sea level, yielding colour infrared photography at a nominal scale of 1:70,000.

A second flight was planned for August of 1975 through CCRS Task Number 75-76, to provide several lines of large-scale (1:6,000) aerial photography. However, inclement weather and technical difficulties prevented the mission from being flown.

The satellite data were recorded by the multispectral scanner on board the Earth Resources Technology Satellite known as LANDSAT-1 (formerly ERTS-1). The scanning system operates in two visible and two

TABLE 1.I

CHARACTERISTICS OF THE REMOTE SENSING DATA

A. Aerial Photography

Date	Sensor	Lens Length (mm)	Flying Height (m)	Scale	Film Type	Filters	NAPL Code
July 23, 1973	Wild RC-10 Camera	86.4	6100	1:70,000	2443	Wr.15 3.3xAV	RSPA 30786 IR
August 1975	Wild RC-10 Camera	152.4	915	1:6,000	2443	Wr.12 2xAV	Aborted

B. Satellite Data (LANDSAT-1)

Date	Sensor	Scale	Bands	Picture Centre No.	Frame Number
July 22, 1973	Multispectral Scanner	1:1,000,000	4,5,6,7	30-20, 30-21	1364-16341, 1364-16344

near-infrared bands and provides imagery at a scale of 1:1,000,000. Of the data available for Pen Island from the summer of 1972 to the spring of 1975, that of July 22, 1973 was of fine quality, and was free of snow or cloud. It also preceded the aerial photography from Task 73-40 by only one day, and therefore had a ready set of near real-time "ground" information for its analysis.

1.4 Outline of the Thesis

This chapter has introduced to the reader the purpose of the investigation, the area where it is carried out and the types of information that are used. The ensuing chapters concern the details of the study, which may be described as an evaluation of colour infrared aerial photography and LANDSAT satellite data for biophysical analysis in subarctic Canada, as it is represented by the Pen Island site.

Chapter II presents a review of the literature that is related to the study. It examines the development and applications of the biophysical concept of environmental analysis, and the use of remote sensing techniques to obtain this type of knowledge for subarctic regions. Also included is an outline of the aspects of field investigations already completed at Pen Island, and in other parts of the subarctic, that are relevant to a programme of biophysical mapping.

Chapter III considers the ground studies carried out by this writer at Pen Island during the field season. The observations are divided into two groups; one discusses aspects of the geomorphology of the area, the other describes the different landscapes types that occur and provides representative illustrations of each one.

Following the discussion of the field investigations, the analyses of the aerial photography and satellite data are reported in Chapters IV and V. Important features of each sensing technique are reviewed, and the procedure and results of the various methods of analysis are studied. Subsequently, the findings of the different approaches are compared and discussed in detail, and conclusions are drawn.

The last chapter, VI, summarizes the investigation and presents the conclusions reached in the study. Recommendations for future work of this type are suggested in the final pages of the thesis.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

An examination of relevant literature is an essential part of any investigation. It serves to fit the work into the context of current thinking in the field of interest, and also provides a basis of knowledge from which the investigation may be carried out. The nature of this thesis, as described in Chapter I, lends itself to a three-fold review of published material. First, it is necessary to look at the idea of an integrated or biophysical type of regional analysis, how the concept arose and how it has been applied. Second, the analysis of remotely-sensed data in an environment like the one encountered at Pen Island should be considered. This involves looking at the different types of data and analysis techniques that have been used and also the nature of the information being sought. Finally, one must examine work that has already been completed at the Pen Island site, and in similar localities, relating to the landforms, vegetation, soils, drainage and other environmental factors. This type of information provides a familiarization with the nature of the area and a source of knowledge in various fields of study that contribute to the biophysical environment.

2.2 Concept of a Biophysical Analysis

There is a considerable variety in the sorts of approaches used for investigation of the environment. At one extreme is the single-discipline study which examines only one feature in isolation, while at the other end is the all-encompassing study which attempts to analyze "spatial totality" (Whittlesey, 1954, p. 45); that is, every aspect of the natural and human components of the environment. In between is a whole range of multi-discipline approaches which look at two or more features in any one of a number of ways.

The concept of environmental analysis used in this thesis falls somewhere in the middle. It is a multidisciplinary one that involves looking at the natural environment as a whole. Termed variously in the literature as an integrated study, a holistic, land or landscape one, an ecological survey, a biophysical, geobotanical or photomorphic one, or quite simply a geographic or regional analysis, the concept is based on the idea that the constituent elements of the environment are closely interrelated. The nature of a certain element is related in some way to one or several other elements. Thus, the aspects of the natural environment - geology, topography, soils, drainage, climate and vegetation - may be integrated or combined to define areas characterized by distinctive combinations of phenomena. These areas are not unique; rather, they are recurrent. Further, they may be identified at a variety of scales, and these may be ordered into a hierarchy of landscapes. If the finest division, representing a detailed local scale, may be termed a unit, then several repeated units may be combined to create a system, and several systems in turn create a region. The latter is a general and broad-scale division of the land.

The landscape categories at any scale are not only mapped in this approach to environmental analysis. They are also frequently examined in terms of the relationship among their constituent elements, and among themselves. Quite clearly, such an investigation should be a co-operative effort, involving experts in a variety of fields of research. The number of such persons is largely dependent upon the scope of the project undertaken and the finances available.

The combined-element study of the natural environment, which this writer prefers to call a biophysical or landscape analysis, is in widespread use at the present time. It has been employed successfully in the planning and management of resources throughout the world, and has also been of value in academic applications that are ultimately directed towards improved resource inventory. While the biophysical approach is suitable for the study of wildlands, modifications can be introduced to include cultural aspects of the environment. These types of integrated surveys have been carried out in settled regions of the Third World as well as in more affluent nations. They are analogous to the biophysical studies, but are not directly important in this review and will not be considered further.

2.2.1 Initial Thoughts: 1900-1915

The concept of a biophysical or landscape analysis has arisen in different locations quite independently but generally at the same time. The earliest ideas that led to its development appeared in the literature in about the year 1900.

In the non-Soviet world, writers in France, Germany and England began discussing regions at the turn of the century (Whittlesey, 1954). They were concerned with geographic elements associated together on the land and the relationship of the physical elements to man (Heath, 1956).

Concurrently in North America, Isiah Bowman published a book entitled *Forest Physiography*, in which he divided the United States into natural or physiographic regions (Bowman, 1911). These were in turn divided into a number of component groupings. The various categories were defined by a combination of soils, vegetation, climate and drainage, these factors being considered together as interrelated phenomena. In subsequent years, Bowman became more interested in the relations of man's activities to the physical environment (Heath, 1956). The same idea of man and the land together appeared in the works of W. M. Davis as he became involved with regions (Davis, 1915).

In addition to the western world, the USSR witnessed a dawning interest in landscape regions near 1900. Dokuchayev is credited with laying the foundations for the development of the field of landscape science in the Soviet Union (Kalesnik, 1962). He called for the study of natural zones or "integrated territorial aggregates" of natural phenomena, rather than individual aspects of the environment.

2.2.2 Early Developments and Applications: 1915-1945

While the early writings in Western Europe and America contained ideas of related natural phenomena, as appear in the modern concept of biophysical analysis, their inclusion of man led to environmental determinism in geographic study. That the nature of man and his activities was determined or controlled by the physical environment became a widespread and very popular idea. The concept was so over-emphasized, however, that a reaction against it took place in the later 1920's. Also significant in its repression was an essay written by Carl Sauer in 1925 (Leighly, 1965), where Sauer presented his ideas on the purpose and content of American geography (Sauer, 1925). He proposed the term "landscape" to denote "an area made up of a distinct association of forms, both physical and cultural" (Sauer, 1925, p. 321). These forms were "not simply assorted, but (were) interdependent" (p. 318). While he included cultural elements in his definition, he stressed that they were not essential. Rather the factors used to define landscapes were dependent upon the purpose of the investigation at hand. A landscape type could be identified by its natural attributes, as in the case of biophysical land units, by its cultural attributes or by a combination of the two.

During the later part of the period between the two world wars, from 1930 onward, aerial photography became available in many parts of the world. With its development, the concept of an integrated landscape analysis received further support. It was especially apparent on the photography that the many aspects of the natural environment were all interrelated. The image recorded on the film was the combined result of many phenomena, any one of which could not be seen without another.

R. Bourne, whose paper of 1931 is discussed by Christian and Stewart (1968), was one of the first users of aerial photography for forestry. In carrying out a forest inventory of the British Empire, Bourne used the early aerial images to identify natural landscape types. These were recognized at two levels, the "site", an area of apparently similar climate, physiography, geology, vegetation and soil, and the "region", an association of several different recurrent sites.

Natural landscape surveys in the United States at this time also employed aerial photography. At the Michigan Agricultural Experimental Station, Sauer and many others were involved with the inventory of state lands for land-use planning. They developed a classification scheme based on "natural land types" in the 1920's, and in the next decade the scheme was put into use. The "land type" was defined as a "natural division of the land surface ... which integrates a number of separate (physical) features" (Veatch, 1937, p. 499). It closely parallels the concepts of the modern biophysical classification systems. As in the later systems, the Michigan one recognized a hierarchy of land groupings, with natural land types being mapped at scales of 1:280,000 and 1:135,000. The land types were identified on aerial photographs or photo-mosaics, in association with field studies. Applications of the classification scheme are described in a number of reports (Nat. Res. Plan. Board, 1941; Davis, 1965).

A similar approach to land inventory was used throughout the mid-western and western United States by the Federal Bureau of Reclamation (Nat. Res. Plan. Board, 1941). The Bureau was involved with the planning of irrigation systems to make the arid and semi-arid lands of these areas suitable for agriculture or other economic activities. They mapped areas of combined natural features (soils, topography, drainage and natural vegetation) at scales of 1:24,000, 1:12,000 and 1:4,800, each level of detail having a specific role in the planning process.

In Canada, H. E. Seely (1947) reviewed forest-survey work with aerial photography over the years 1930 to 1945. He devoted only a small paragraph to the forest-site technique, noting that little had been done using a landscape approach.

Although it was not employed in practical forest inventory, the biophysical means of mapping Canadian forests did appear in the literature in the 1930's. Halliday (1937) devised a forest classification that was essentially a series of geographic descriptions. He divided the forested part of Canada into "forest regions", defined by a particular climate and climax vegetation, and then divided these into "forest sections", defined by a broadly uniform plant association as well as soils, geology, and local climate. Although Halliday only included written descriptions in his report, his categories of forests were cartographically displayed by Rowe in 1959 and again in 1972 (Rowe, 1959; 1972). Portraying the forest regions at 1:19,000,000 and the forest sections at 1:6,300,000, Rowe introduced more recent knowledge to the original work of Halliday, but he found that it produced little modification.

2.2.3 Recent Developments and Applications: 1945-1976

From the late 1940's to the present, the biophysical approach has grown into a popular and well-defined means of environmental analysis. Two factors appear to be responsible for this growth. First, there has been a great increase in the amount and types of remotely-sensed information available. As already noted, the aerial perspective is highly suggestive of the need for an integrated study of the environment. Second, there has been a large upsurge of general concern for environmental protection over the past 15 years, and this has created a need for the inventory of natural resources.

a) The Australian CSIRO

An important development in the popularization of landscape analysis is the work of the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO). Beginning in 1946 under the leadership of C. S. Christian, CSIRO devised a scheme of land-resource survey for use in the extensive undeveloped parts of Australia. The system relied heavily upon the use of aerial photography but also involved field survey. Christian and his co-workers set forth the term "land" to refer to the integration of the "land surface and all its characteristics of importance to man's existence and success" (Christian and Stewart, 1968, p. 238). The various elements of the physical environment were combined to create "land units", small areas of distinctive nature that were recognizable on aerial photographs. An association of land units produced a recurring pattern of landscapes that was termed a "land system". There was, therefore, an ordering of landscapes with the land unit representing a scale of 1:50,000 to 1:100,000 and the land system a scale of 1:250,000 to 1:1,000,000.

This approach to resource survey was applied initially by Stewart and Christian in 1946 to the Katherine-Darwin area of Northern Australia (Stewart and Christian, 1968). It has since been used throughout central Australia and New Guinea by CSIRO (for example, by Grant (1968) in Queensland, Haantjens (1968) in Papua and New Guinea, and Perry et al. (1962) near Alice Springs). The method has proven to be highly successful, and has been adopted by the United Nations and other overseas agencies for use in much of the underdeveloped world. The United Nations FAO has employed the technique in West Cameroon (Brunt, 1968), UNESCO has used it in Pakistan and India (Christian and Stewart, 1968), and Oxford University has used it in much of Africa (Webster and Beckett, 1970).

The value of the integrated aspect of biophysical analysis is well demonstrated by a resource mapping programme in Chile that employed the CSIRO approach. Investigators from the University of Colorado found many recently completed single-resource maps to be of little value for planning (MacPhail, 1971). They could not be correlated to define recognizable and workable units. As a result, MacPhail and his associates decided that the Australian concept of landscape would be useful. They modified it to include certain cultural features, and then produced maps of "photomorphic units" from field and airphoto study. Originally drawn at a 1:100,000 scale, the multidisciplinary maps have been valuable sources of information for recent planning and development purposes.

b) The United States

In the continental United States, comparatively little has been done since the early Michigan work to advance the biophysical means of environmental analysis. This is understandable, as the percentage of undeveloped and relatively unknown land in the country is far less than in many other nations. Nevertheless, some of the more remote localities have been examined by the landscape approach. Wilson and Berard

(1952) mapped wildlife habitats in the Appalachians of West Virginia and the state of Oregon inventoried its rangelands following a land-plant classification system (Am. Soc. Photogram., 1975). A biophysical method was adopted by Kolipinski et al. (1969) for environmental preservation studies in the Florida Everglades, while the photomorphic scheme of MacPhail was applied to northwestern Colorado by Nichol (1975).

With the current interest in exploitation of its resources, the state of Alaska has begun to use the landscape means of environmental survey. As early as 1946, the University of Alaska developed a "land-classification where the natural vegetation was highly significant" (Stone, 1948, p. 465) but where other aspects of the physical environment were also included. Their mapping was done from aerial photography at a scale of 1:30,000 to 1:50,000. More recently, large resources inventories have been started throughout the state. Although these involve an interdisciplinary team of experts working together, generally they map individual aspects of the environment (for example, vegetation, surficial geology and drainage) and later compare the results (Anderson et al., 1973; Miller and Belon, 1973). This type of integration is rather different from the biophysical approach. Some phases of the work have employed landscape classifications,however; notably for the delineation of animal habitats and permafrost terrain units.

c) The USSR

The USSR, since the time of Dokuchayev, has independently developed a very strong science of landscapes. By 1959, it was well established and widely employed (Kalesnik, 1962). The earliest mapping of landscape units from aerial photography was completed in 1931, at the same time as the study of Bourne in the British Empire (Vinogradov, 1969). At present, the landscape approach of the Soviet Union is very similar to that of the western world. Scientists chiefly use remote sensing to map multidisciplinary units of the land surface at a variety of scales, with each level of detail being defined by a combination of classes in the adjacent higher level. The hierarchy includes the "facies" at a scale of 1:5,000 to 1:10,000, the "unit" at 1:25,000 to 1:50,000, the "site" at 1:100,000 to 1:200,000 and an unnamed class at 1:400,000 to 1:1,000,000. Several examples of Soviet landscape analyses of the natural environment are found in *Use of Aerial Methods in Landscape Studies* (Viktorov et al., 1969), a technical translation of the original Russian publication by Viktorov in 1959.

d) Canada

As in other parts of the world, investigators in Canada have applied the idea of an integrated land classification to the analysis of undeveloped regions. The work of Hare (1959) in Labrador-Ungava is an excellent example from the 1950's. Following the discovery of iron ore in the vast, unknown region of Labrador-Ungava in 1949, a reconnaissance project was launched to look at the geography of the area. With Hare as the senior investigator, the survey took shape as an interdisciplinary study designed to map cover type and surface-physiographic type from aerial photography, along with limited field study. The group devised a unit for mapping that was termed a "cover-type", an area defined by a certain pattern of vegetation, soil moisture and characteristic terrain associations. Initially photo-interpretation keys were produced, and these were used to analyze 1:60,000 aerial photography. The results were then transferred to a map base at a scale of 1:507,000.

The methodology of the Labrador-Ungava study was employed by Ritchie (1962) for his survey of northern Manitoba in the later 1950's. In his work, landforms (slope, drainage, soil, and permafrost conditions) and vegetation were mapped simultaneously from airphoto and field analysis. The resultant divisions of the land were "geobotanical units", recognizable at a 1:507,000 scale.

Concurrently in Ontario, G. A. Hills (1952, 1960) led a forest evaluation programme aimed at the management of the forests for continued and improved commercial operations. A forest-site classification was generated which integrated the physiographic-site type (climate, soil, topography and geology) and the forest type (tree cover and lesser vegetation) to form the "total-site type", a distinct ecological unit where a particular forest type grows in a particular physiographic-site type. Several repeated site types produced a "site district", and several site districts produced a "site region". These were mapped at approximate scales of 1:63,000 to 1:210,000, 1:4,000,000 and 1:12,700,000 respectively.

Towards 1960, interest in the mineral exploration and resource exploitation of Canadian wildlands continued to increase. As a result, the federal government began to develop a means of natural resources inventory for the unsettled regions of the country. It was the purpose of the inventory to provide a collection of base data that could be used for many different purposes (for example, wildlife and waterfowl habitats, forestry, agriculture and recreation). Lacate (1966) and Gimbarzevsky (1966) published separate but similar approaches to the problem during the development period. These involved the mapping of landscapes from aerial photography. Their ideas and those of other people of the National Committee on Forest Land were tested in many pilot projects across Canada. In 1969, a manual was produced describing the biophysical land-classification system devised by the Committee (Lacate, 1969). This system divides the landscape into ecologically-significant units that are a combination of landforms and landform patterns, soils and vegetation. They are identified by means of airphoto interpretation and field work. The landscape groupings are ordered into a four-tier hierarchy, each tier being a union of classes at the next more specific one. Essentially the classification system is as follows:

(i) the "land type", a generally localized area of a particular parent material, with a fairly homogeneous combination of soil (at the soil series level) and vegetation, best mapped at a scale of 1:10,000 to 1:20,000 in most cases;

(ii) the "land system", an area of a recurring pattern of landforms, vegetation and soils that can be shown on maps at a scale of 1:125,000 to 1:250,000;

(iii) the "land district",an area of a distinctive pattern of relief, geology and geomorphology, and associated regional vegetation, mappable at scales of 1:500,000 to 1:1,000,000;

(iv) the "land region", a generally large and heterogeneous area of distinctive regional climate, as expressed by vegetation, suitable for mapping at a scale of 1:1,000,000 to 1:3,000,000 or smaller.

This biophysical classification system for study of the natural environment has been employed in numerous investigations in Canada since its first appearance in 1969. These include the landscape analyses of Thie and his associates in northern Manitoba (Thie et al., 1974; Thie, 1976), of Gimbarzevsky (1974) in a large area north of Jasper, Alberta, and of Jurdant (1974) in the southern Laurentian district of Quebec. Other examples are provided by the biophysical mapping programmes of Day and his associates in Banff and Jasper National Parks (Kirby et al., 1975) and of Crampton (1973) in the Mackenzie Valley. At the present time, a national committee is being organized to deal with the continued development and application of the biophysical land-classification system throughout the country (Thie et al., 1975).

In recent years, several other variations of the landscape means of environmental analysis have been used across Canada. Lavkulich (1973) delineated units of similar natural phenomena on airphoto mosaics at a scale of 1:63,000 for the Wrigley area of the Mackenzie Valley. Dirschl and Coupland (1971) mapped landscape patterns of the Saskatchewan River Delta at a 1:37,000 scale. Subsequently, Dirschl, Dabbs and Gentle (1974) studied the Peace-Athabasca Delta, classifying the landscape into "land systems" at 1:37,000 and "land facets" at 1:10,000. While the facet is stated to be equivalent to the land type of Lacate (1969), the system does not correspond exactly with the Lacate land system, which is mapped at a considerably smaller scale. Rather, this new land system is apparently a means of simplifying the landscape, for the classes are merely broad cover types such as coniferous forest versus grasslands.

2.3 Remote Sensing of Landscapes in Subarctic Regions

As may be inferred from the preceding pages, the landscape approach to environmental analysis relies heavily upon remote sensing as a source of information. A number of the currently available techniques in remote sensing have been applied to biophysical surveys throughout the world. This is the case in the subarctic environment of North America, in Canada and Alaska. While it may be assumed that extensive work of this kind has been done in the USSR, the literature is generally inaccessible and will not be considered in this section.

Traditionally, integrated landscape studies in the subarctic have employed panchromatic aerial photography at an average scale of 1:60,000. In Canada, this is the standard scale used by the National Air Photo Library for photography in unsettled regions. The work of Hare (1959) in Labrador-Ungava and Ritchie (1962) in northern Manitoba during the 1950's are good examples. R. E. Frost and other members of the US Army Cold Regions Research and Engineering Laboratory (Frost et al., 1963), as well as Stone (1948), also employed relatively small-scale panchromatic photography to examine landscape patterns in Alaska.

A substantial amount of work was carried out in the 1950's and early 1960's using the various landscape elements recorded on the photography to predict permafrost conditions for a variety of purposes. Raup and Denny (1950) examined vegetation and topography in Alaska to infer permafrost and many other geologic factors significant to engineering. In Canada, Mollard (1960), Pressman (1963) and Fletcher (1964) were involved in similar projects, looking at a number of components of the environment related to engineering. Sager (1951) in particular stressed the need to evaluate all elements visible on the photography collectively, not independently, in order to solve problems. These investigations all used conventional panchromatic aerial photography at a scale of about 1:60,000. While they did not actually map landscape units in the sense of Hare or Ritchie, they did use the landscape approach to obtain the information they needed.

Panchromatic aerial photography has been established as a very valuable means of obtaining data for subarctic regions. The most readily available, the cheapest and the most widely understood of all types of remote sensing, the conventional black and white images continue to be widely used to the present day, even though more sophisticated techniques have been in existence for some time. Brown's surveys of the permafrost landscapes across Canada, begun in 1962 and lasting for several years, provide a fine illustration (Brown, 1964; Brown, 1968). More recently, the Task Force on Northern Oil Development has employed panchromatic aerial photography extensively for its examination of the Mackenzie Valley. Crampton (1973) mapped biophysical land units in the upper and central Mackenzie Valley from panchromatic images, and Watson and his associates used a similar technique to provide an inventory of wildlife habitats in the area (Watson et al., 1973).

While the usefulness of conventional panchromatic aerial photography cannot be refuted, a number of other techniques of remote sensing are being assessed for biophysical mapping in the subarctic. These sensing methods may increase the precision, reduce the time requirements or provide additional or different information.

Photographic remote sensing using film and filter combinations other than the panchromatic one have been used in the subarctic since the late 1960's. These techniques include multiband (usually green, red and near infrared), colour and colour infrared aerial photography. When they first became available, these types of remote sensing data were poorly comprehended. Early in 1972, Mollard (1972) reviewed airphoto terrain classification and mapping programmes being carried out in northwestern Canada for pipeline studies. He concluded that while non-conventional photography was needed and should provide additional information, the panchromatic type was still superior, since it had been in use for many years, was better understood and gave reliable results.

In response to the situation described by Mollard, there have been many investigations carried out to evaluate the information content of the newer types of remote sensing for landscape analysis. Various scales of multiband, colour and colour infrared photography, and also panchromatic in some cases, have been examined by Dirschl, Dabbs and Gentle (1974) in the Peace-Athabasca delta of northern Alberta, by Pakulak et al. (1974) in northern Manitoba, and by Thie and Tarnocai (Tarnocai, 1972; Thie, 1972; Tarnocai and Thie, 1974; Thie et al., 1974) in northern Manitoba. All of these studies showed colour infrared aerial photography to be the best for biophysical mapping in northern areas. Similar conclusions were reached by Pakulak and Sawka (1972) in Manitoba for the Oak Hammock Marsh. This area is a freshwater wetland, as is Pen Island, but it exhibits a somewhat warmer boreal environment. The suitability of colour infrared film for landscape analysis in these vegetated areas is related to its sensitivity to the near-infrared, which reveals variations in vegetation and moisture conditions better than the visible wavelengths of radiation.

Remote sensing of the non-photographic part of the electromagnetic spectrum has received much less attention than the photographic part for biophysical mapping. Thermal infrared imagery has been studied by Tarnocai and Thie (1974) in the discontinuous permafrost zone of Manitoba. They were able to detect vegetation types and surface moisture conditions. They could not, however, locate permafrost directly on the imagery, despite the fact that thermal IR provides some indication of surface temperature. Permafrost is a subsurface phenomenon that is covered by soils and vegetation with highly variable thermal properties of their own. Thermal infrared imagery may in some instances provide specialized information about the environment, but for landscape analysis in general it ranks far behind many other sensing systems at the present time.

Radar imagery, like thermal IR, senses in the non-photographic wavelengths. It is currently very restricted in availability and has therefore rarely been applied. Thie (1974) looked at radar images of the same area of Manitoba mentioned above, and concluded that it held little promise for biophysical analysis of the environment.

The newest type of remote sensing data is satellite imagery. Being recorded from spacecraft, it is at a much smaller scale than data obtained by aircraft remote sensing. As a result, it yields extensive coverage of the earth's surface on a single image.

The first satellite imagery became available in the 1960's with the launching of the orbital weather satellites. These were specifically designed to provide coverage of cloud systems rather than the earth's surface; hence the imagery had very low ground resolution. In spite of this lack of detail, weather analysts noted the repeated occurrence of an east-west line across northern Canada, which they assumed to be the treeline. Aldrich, Aldrich and Rudd (1971) examined the nature of this line using ESSA and Nimbus satellite imagery from 1967 to 1969. They found that it corresponded well with the transitional zone between the boreal forest in the south and the treeless tundra in the north, as it had been mapped by Hare (1959) in Labrador-Ungava, by Ritchie (1962) in northern Manitoba and by Raup in 1946 in the Great Slave Lake-Lake Athabasca district. Their "forest-tundra" ecotone is an environment much like that at Pen Island. While no details could be seen on the weather satellite imagery, there was an indication that space-acquired data with higher ground resolution would be valuable for environmental investigation.

In July of 1972, the first orbital Earth Resources Technology Satellite (ERTS-1) was launched into space, followed by ERTS-2 in January of 1975. Presently these systems are referred to as LANDSAT 1 and LANDSAT 2. Unlike the weather satellites, they contain sensors designed to yield imagery in the photographic wavelengths of the earth's surface. The LANDSAT data have high spatial resolution and a large scale relative to imagery from other satellites. They are originally recorded in numerical form, and are therefore suitable for visual or digital techniques of analysis.

Several investigations of LANDSAT data for biophysical analysis have been carried out in Alaska and Canada. Those in the northern boreal as well as the subarctic regions are worthy of consideration, since the two environments grade into one another and the results of one may be applicable to the other. Alaskan projects include those of the federal wildlife bureau (Van Tries, 1973) and the US Army Corps of Engineers (Anderson et al., 1973) throughout the state, and the University of Alaska in the transportation corridor from Prudhoe Bay to Valdez (Miller and Belon, 1973). Canadian investigators have examined western Alberta in the vicinity of Banff and Jasper National Parks (Gimbarzevsky, 1974; Kirby et al., 1975), as well as the Telegraph Creek area of northern British Columbia (Valentine and Hawkins, 1975) and the Clay Belt northwest of Timmins, Ontario (Boissonneau and Jeglum, 1975). Thie et al. (1974) studied the Mackenzie Delta area and also northern Manitoba, and Steffensen (1975) analyzed a number of locations along the Mackenzie River.

In general,these investigations all stress the vital need for LANDSAT data in the analysis of extensive unknown and often inaccessible regions. The comparative study of Valentine and Hawkins (1975) illustrates the substantial savings in time and money that can be achieved through the use of LANDSAT imagery rather than aerial photography for mapping at a general or land system level.

The information content of LANDSAT was found to be surprisingly high in many of the analyses, given the scale of the data. Anderson et al. (1973) produced maps at a scale of 1:1,000,000 of permafrost terrain types that were considerably better and more detailed than those previously available. Thie et al. (1974) found the data of the Churchill area in Manitoba to be so specific that they had to be grouped into larger units for effective mapping.

Although LANDSAT data may contain much information, the classes recognized in their analysis do not always correspond exactly with those already mapped from other sources of information. This is the case in the work of Steffensen (1975). The LANDSAT classes are not necessarily wrong in this situation. Rather, they may simply represent a type of classification that is different from the existing one.

The scales of mapping for which LANDSAT data are suitable vary. In the mountains and foothills of Alberta, Gimbarzevsky (1974) and Kirby et al. (1975) concluded that mapping at the land region (1:1,000,000 to 1:3,000,000) or land district (1:500,000 to 1:1,000,000) levels yielded good results. Thie et al. (1974), on the other hand, were able to delineate land systems (1:125,000 to 1:500,000) in extreme northern Manitoba, as were Boissonneau and Jeglum (1975) in northern Ontario. Valentine and Hawkins (1975) also mapped land systems successfully in B.C. Investigators who mapped units at the system level could in fact detect a few land types (1:10,000 to 1:20,000), but they reasoned that mapping at such a large scale from LANDSAT data was not practical.

A number of writers consider the maximum scale for biophysical mapping from LANDSAT data to be related to the degree of complexity of the landscape. Using digital techniques, Thie et al. (1974) were able to precisely map land systems in the relatively simple arctic and subarctic landscapes but could not in the more complex boreal one.

Gimbarzevsky (1974) also found that less complicated areas could be mapped in greater detail than the surrounding region.

Whether the visual or digital means of analysis was used, most of the LANDSAT projects previously described concluded that better results could be achieved through the examination of data from many dates or bands instead of one date or band. Boissonneau and Jeglum (1975), who used only Band 5 data and found some confusion among their classes of wetlands, may well have overcome the problem by employing data from other bands as well. Several different systems were utilized in the studies involving digital analysis, and each gave satisfactory results. Comparing the visual and digital techniques, Thie et al. (1974) found that biophysical land systems could be correctly mapped by digital means in the arctic and subarctic, where relationships among the constituent elements are fairly simple. In the more complicated boreal environment, however, visual methods produced a better landscape classification. The visual approach to LANDSAT analysis was considered more practical than the digital one in terms of time and money, regardless of the type of landscape (Thie, 1976).

Finally, a point emphasized in all of the investigations is the need for accurate ground truth in the form of aerial photography and/or ground survey. Such base data are essential, since landscapes can be delineated by LANDSAT analysis, but they require other sources of information for their identification and description.

2.4 Ground Studies at Pen Island and in Similar Locations

Since 1970, the Department of Biology at McMaster University, in conjunction with the Department of Geography, has been carrying out a series of detailed investigations in the Hudson Bay Lowlands. The examinations of plant ecology and associated microclimatology by this group were initiated in northeastern Ontario at Hawley Lake and Cape Henrietta Maria (Figure 2.1). With the establishment of a large provincial park in the area, however, the group was forced to move elsewhere in the following year. A suitable site of similar nature was found in extreme northwestern Ontario on the mainland opposite East Pen Island. This area had recently been made accessible by aircraft due to the offshore drilling operations of one of the large oil companies and the resultant establishment of a base camp and airstrip near the coast. Facilities of the camp were made available to the McMaster team during the first and all subsequent seasons.

The work of Drs. K. A. Kershaw and W. R. Rouse and their students provides an important body of information for this thesis. The knowledge of plant types and related environmental conditions, as required for a landscape analysis of remotely sensed data, has been gained from the studies and field experience of these people. Various aspects of their work are subsequently described.

The research programme of Kershaw and Rouse began with the intention of carrying out detailed studies of the vegetation and its interaction with environmental parameters. Initial visual observations of vegetation communities suggested that each was a very homogeneous grouping of plants. Species counts at several locations within each

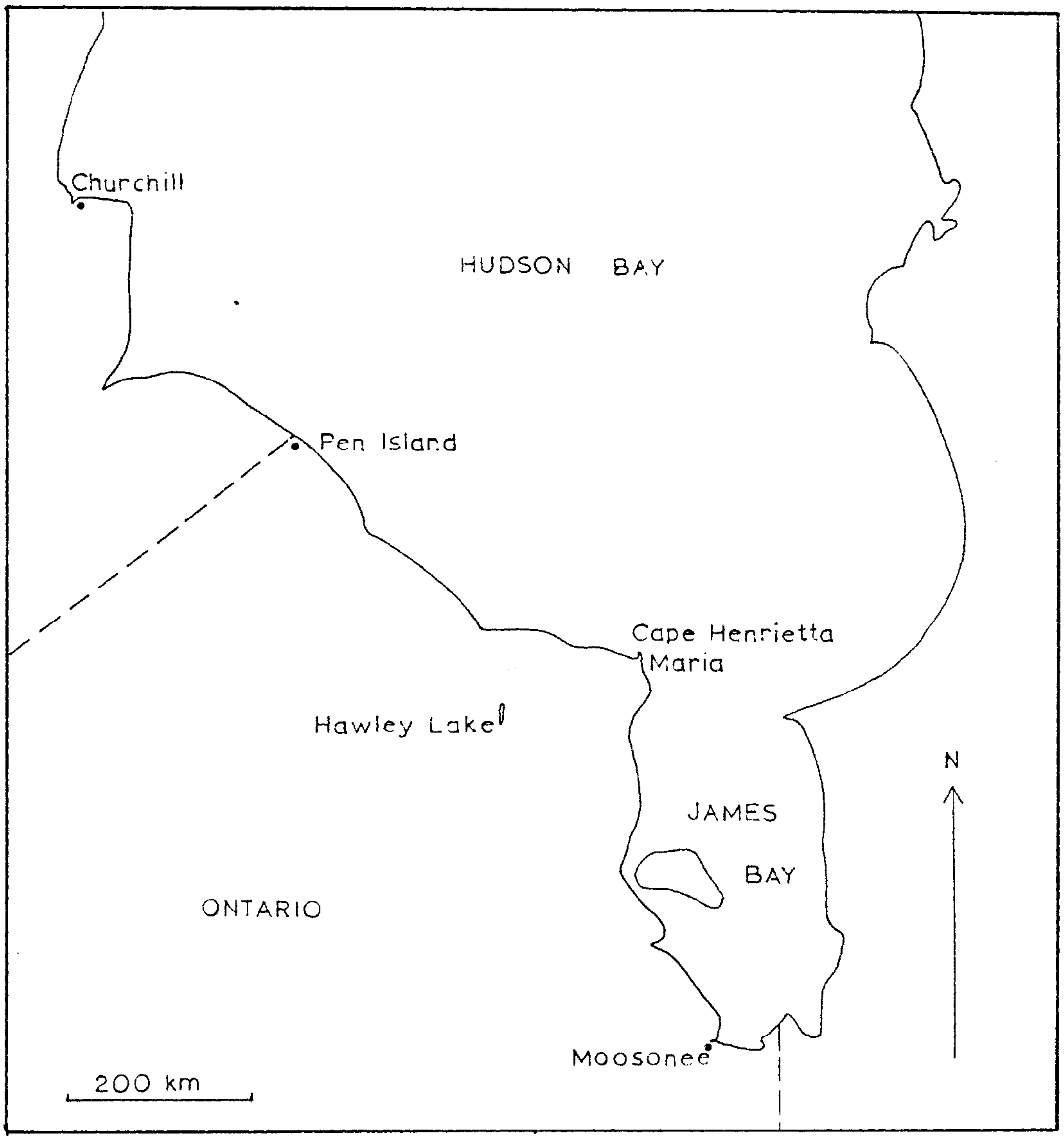


Figure 2.1 The location of McMaster University research sites in northern Ontario

group revealed that the apparent uniformity was generally quite misleading, there being many different plant associations in each one. Further examination of aspects of the local environment was necessary in order to explain the heterogeneity. This has included investigations of soil moisture conditions, topography and its effect on microclimates, the depth of peat accumulation and also the heat and water regimes of different surfaces. The detail involved in this research is an order of magnitude greater than that required by this writer. For the present investigation, it is the "apparently homogeneous" units that are of interest. The basic descriptions of these units, as they appear in a number of papers, are useful, as are some of the discussions therein.

Kershaw and Rouse (1971a,b) and Rouse and Kershaw (1971) studied three landscapes at Hawley Lake that also occur at the Pen Island site but are not easily accessible there. These include:

(i) the spruce-lichen woodland, an area of widely-spaced black spruce trees (*Picea mariana*) with a ground cover of almost pure *Cladonia alpestris* lichen;

(ii) the recent burn of the spruce-lichen woodland, essentially a charred and ashen surface burned at least 3 years before; and

(iii) the old burn of the spruce-lichen woodland, an area of widely spaced, recolonizing spruce trees (*Picea mariana*) with a ground cover of low shrubs and mixed lichen species, and with 10 percent bare ground, burned at least 16 years before.

All three landscapes are confined to high or sloping ground where the soils are well drained.

The plant ecology of the raised beach ridges has been studied at length at Pen Island (Kershaw and Rouse, 1973; Rouse and Kershaw, 1973; Larson and Kershaw, 1974; Kershaw and Larson, 1974) and to a lesser degree at Cape Henrietta Maria (Neal and Kershaw, 1973). The newest relic ridges are only partially vegetated, primiarly with the xerophytic *Dryas integrifolia* plant, and in some parts they are barren where blowouts have occurred. Generally, however, these dry upland sites are a lichen heath. There are a number of plant associations within this unit of vegetation, with different lichen species predominating, depending on the environmental conditions.

Other communities examined at Pen Island include the sedge meadows, low wet areas located between the relic ridges (Kershaw, 1974) and the saltmarsh (Kershaw, 1975). The sedge meadows are composed of sedges (*Carex sp.*) and mosses, with lichens and shrubs growing on drier hummocks within the meadows. The saltmarsh has three zones, with different vegetation communities being related to the frequency and duration of saltwater innundation. The upper salt-marsh is a transitional zone where a number of freshwater plants are present as well as the saltwater ones.

A number of other papers contain useful background information for the study of landscapes at Pen Island. While these do not concern the Pen Island area directly, they do describe similar environments in other locations. The terminology used by Kershaw and Rouse to describe the vegetated landscape at Pen Island is virtually identical to that used by Hare (1959) in northern Quebec and Ritchie (1962) in northern Manitoba. These authors present good descriptions of vegetation, topography and drainage conditions for all landscapes in their areas, covering some only briefly mentioned by the McMaster researchers. Further, their data are listed in a convenient chart form. Sjors (1961) also wrote helpful descriptions of the subarctic environment in the Hudson Bay Lowlands.

Perhaps the most beneficial material other than the McMaster work is an essay presented to an organic soils workshop by C. Tarnocai (1974). In it, Tarnocai describes a detailed classification of peat landforms and their associated vegetation. He also includes many diagrams and photographs for illustrative purposes. Peat landforms constitute almost the entire landscape at Pen Island. The proportion of area covered by saltmarsh or dry upland forms is very small in relation to that covered by peaty wetland types.

2.5 Summary and Conclusions

This chapter has examined the biophysical approach to environmental analysis and its reliance upon remote sensing as a source of information. Applications of the concept to subarctic North America have been reviewed in terms of the remote sensing techniques they have employed, and existing knowledge that could contribute to the biophysical analysis of the Pen Island area has been studied.

Biophysical or landscape analysis identifies combinations of interrelated natural phenomena at a variety of scales. These different levels of information are ordered into a hierarchy, with classes in each level being a subdivision or combination of classes in the adjacent level. The concept arose in a number of locations independently around the year 1900. It received considerable impetus for growth in the 1930's when aerial photography first became available. The aerial perspective of the images was suggestive of combined-element mapping, and aerial photography soon became the major source of information for landscape analysis.

Biophysical investigations in subarctic Canada and Alaska demonstrate the variety of remote sensing techniques that are now being employed in such work. Colour infrared aerial photography has proven to be the best all-purpose sensor for landscape mapping, although the original panchromatic type continues to be useful. Thermal infrared and radar imagery are of little value at the present time. Currently, LANDSAT satellite data are being examined to evaluate their suitability for biophysical analysis in northern North America.

The Pen Island district of northwestern Ontario, which exhibits a subarctic wetland type of environment, has not been subjected to biophysical mapping in the manner described in this chapter. There is, however, a large body of specific biological data available for the area. It is suggested that this detailed information on the plant ecology be used to carry out an investigation of several remote sensing techniques for the biophysical analysis of the area.

CHAPTER III

FIELD INVESTIGATIONS

3.1 Introduction

An important and very necessary aspect of the remote sensing study is the attainment of "ground truth". This is the term used to describe accurate information about the earth's surface that is obtained through field study. Ground truth is gathered at the most convenient locations within an area of study, and is then correlated with remote-sensing data. Using this information, similar less accessible areas can be studied directly on the aerial images without having actually been seen.

At Pen Island, there has been a continuing programme of environmental investigation for a number of years, but the area has not yet been considered from a geomorphological point of view. There have only been casual references to the landforms, and little mention has been made of geomorphic processes. Yet this information is useful for biophysical analysis, in order to understand the types of landscape patterns that have developed and that are apparent on the remotely-sensed images. The variations in tone on the Pen Island images are directly a result of differences in the vegetation cover, and these are in turn at least partially an expression of differences in the geomorphology. Hence, part of the field session was devoted to the observation of geomorphological forms and processes.

The second part of the field season at Pen Island involved the examination of landscape types, since these are what are seen on the remote-sensing data. While the geomorphology is one aspect of the landscape, so are a number of other elements of the environment, many of which have already been studied. For biophysical analysis, these elements should be observed together in the field for the different landscapes.

Throughout this chapter, many references are made to specific places at Pen Island. Figure 3.1 is presented to permit these places to be located with respect to one another.

3.2 Geomorphological Investigations

The most important factor in the genesis of landforms at Pen Island has been the coastal geomorphology. Since the area is undergoing isostatic uplift, the active coastline is continuously being raised to the point where coastal processes cease to operate and other types of geomorphic activity begin to take place. At the same time, a previously submerged piece of the earth is exposed to form the new coast. Thus, the Pen Island site is one of active and relic coastal landforms, the latter of which are undergoing modification by a number of non-coastal processes. These primarily include aeolian, fluvial and periglacial types of activity. Within this framework, a series of qualitative observations of the geomorphology at Pen Island were made during the field season.

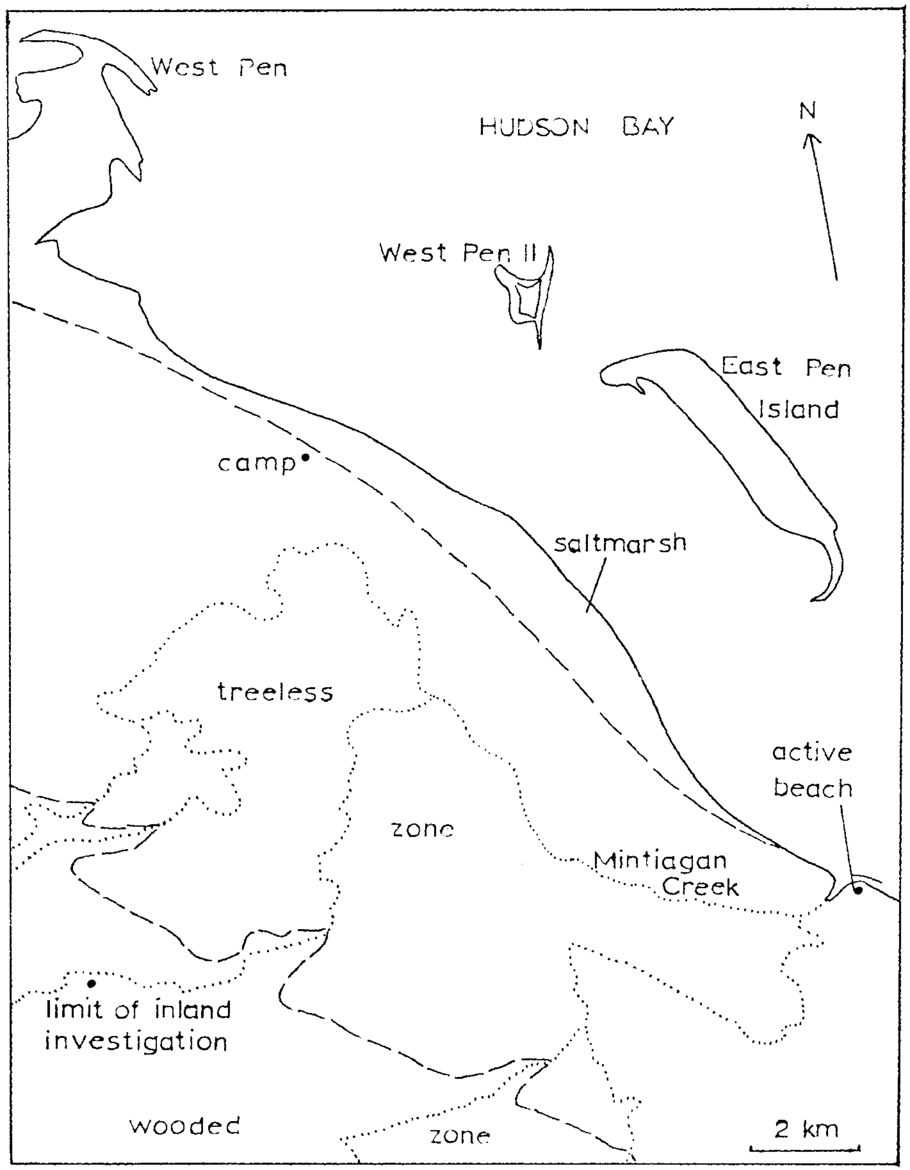


Figure 3.1 The site of field investigations at Pen Island

3.2.1 Coastal Geomorphology

The modern coastline at Pen Island is a low flat type characterized by a number of barrier islands and barrier beaches that have saltmarshes or lagoons on their leeward sides. A study of the forms and processes along the active coast should yield information that is applicable to the relic shorelines now preserved further inland.

In terms of coastal processes, winds are very important, since they generate the waves that act along the shore. During the field season at the Pen Island site, winds were strong most of the time, with calm conditions lasting for only one day out of the fourteen-day visit. A storm took place on August 26 that was accompanied by winds averaging at least 45 km per hour from dawn until early evening. Wind direction over the two-week period was most frequently from the north to northwest, especially during times of stormy weather. This is extremely important for wave genesis, since these are onshore winds. When they are strong, they result in high-energy waves approaching the coast, as well as surging water piling up on the shoreline.

The storm of August 26, which was typical of the early fall season (Canada Dept. of Env., 1974), attests to the high energy of the onshore storms. On that day, large breakers were visible seaward of the camp, and the waters of Hudson Bay were driven high up into the saltmarsh to parts not water-covered at any other time. The breakers continued to roll in for most of the next day even though the storm had passed the evening before. When the storm waves subsided, low ridges with water on their leeward sides were visible offshore. These had not previously been seen, and were apparently storm ridges thrown up by the breaking waves. Further evidence of the high energy of the storm waves was observed along the active beach east of the camp (Figure 3.1). The beach there was composed of coarse shingle after the storm, and it had been washed over along most of its length, although its crest stood 1.8 m above the average high tide mark.

East Pen Island and the active beach to the east of the camp are storm ridges that have been generated during high-energy periods and then built up or modified during times of lower energy. Composed of coarse-grained material, both beach systems have been elongated by longshore currents and have developed recurving spits. As they become older and isostatic recovery of the land continues, they should fan out at one or both ends, as is presently taking place at West Pen. King (1969) attributes this development to the changing patterns of wave refraction as the sea continues to recede.

When the storm ridges are first created, lagoons are formed on their leeward sides. These are areas of calm water where fine suspended sediment gradually settles out and decreases the water depth. In time, if the storm ridges are not removed by the waves and currents, saltmarsh vegetation begins to appear in the lagoons, growing from landward to seaward in response to the slope of the land and the degree of saltwater inundation. At the modern beach east of the camp, a small saltmarsh about 200 m in width is developing between the storm ridge and the mainland. The saltmarsh is not yet completely vegetated; rather, it has many primary pans of bare mud,especially in the low parts adjacent to the ridge. Several of these contain shallow pools of seawater. A similar but much larger saltmarsh is forming in the lee of East Pen Island. This marsh spans a distance of nearly 1.6 km at its widest point. As it grows seaward, another saltmarsh community is growing landward from the island. Presently the two are separated by broad tidal flats and a deep tidal channel, but in time they will meet, as they already have at West Pen.

The modern coastline at Pen Island, therefore, is one of storm ridges and saltmarshes or lagoons. The ridges gradually develop a growth of xerophytic vegetation that helps to stabilize them, and the lagoons gradually fill in with aquatic plants and become saltmarshes. As in the case of West Pen, the older saltmarshes develop well-defined drainage systems which flow parallel to the storm ridges until they reach the ends and the open sea. With the continued rising of the land, the active ridges and saltmarshes become relic features and are no longer affected by waves or saltwater. The drainage systems of the saltmarshes cease to carry saltwater, but the channels may be preserved and become courses for freshwater flow. With the fossilization of these coastal features,the same processes that created them begin to create a new set of coastal phenomena.

3.2.2 Aeolian Geomorphology

The strong and frequent onshore winds that generate high-energy waves and surging waters at Pen Island also have a direct geomorphic effect on the landscape. They produce a variety of aeolian features on the modern and recently fossilized beach ridges. In these areas, the vegetation cover ranges from thin to non-existent, and the sand and gravel material is very dry. Combined with their direct exposure to onshore winds, these areas experience considerable aeolian activity.

Along the modern coastline,the winds heighten the storm ridges by building dunes and thereby decrease their chance of removal by wave action. From the camp, the skylines of West Pen II and East Pen Islands appear uneven, rising to peaks in areas of dune formation. Large dunes are also present along the first relic ridge near the camp, the greatest of which attains a height of 15 m and forms a distinctive landmark in the area.

The large dune complexes of the modern and recently active ridges become targets of wind erosion as their height continues to increase. The sparcely vegetated dunes near the camp are characterized by blowouts on the windward side. Many of these reach a depth of 3 m or more. Smaller blowouts have developed on many of the ridges up to 3.5 km inland, generally where strong winds and animals have broken the thin plant covering.

A number of microfeatures have been created by the wind along the youngest relic ridges. These include saucer-shaped depressions with a lag of large cobbles, in areas where the plants grow in isolated clusters, and erosional arcs, in areas where there is a scrubby but continuous mat of vegetation. The erosional arcs are gregarious features that have a bare face about 15 cm high and 30 to 150 cm long oriented perpendicular to the direction of the prevailing winds (Figure 3.2).

3.2.3 Periglacial Geomorphology

Periglacial forms and processes are present throughout the Pen

Figure 3.2 Small-scale erosional arcs on relic beach ridges near the coast

Island area. According to Brown (1967, 1968), there is continuous permafrost in this part of northwestern Ontario extending from the coast inland for a distance of 60 to 70 km. The entire area of study lies within this zone; however, there exist certain features in its southern half (15 to 30 km inland) which signal the melting of permafrost in a few localities. The majority of field observations of periglacial phenomena were confined to the treeless area near the coast, since the inland wooded zone was largely inaccessible from the camp.

In the vicinity of the camp at Pen Island, the depth of the active layer was examined using a cylindrical metal tube. The results approximate the maximum depth of thaw for the 1975 season, as they were made in late August at the end of the summer. Probing of the recently fossilized ridges near the camp was completed to a depth of slightly over 1 m, yet permafrost was never reached. Experienced investigators in the area believe the depth to be near 2 m (Kershaw and Rouse, 1973). In the adjacent sedge meadows, probing was carried out at exposed, submerged and ice-cored sites. In every case, frozen ground was reached at a depth of 1 m or less, and over areas uplifted by ice lenses, the depth was only .5 to .65 m.

The difference in the depth of the active layer between the ridges and the sedge meadow is related to variations in the depth of peat accumulation and the soil moisture conditions. Pits dug into the ridges revealed only 1 to 1.5 cm of peat atop dry sandy material. In the meadow, on the other hand, the pits showed peat accumulations of 6 to 20 cm over very wet silty clay. Due to the thicker peat and abundant moisture, the meadow has better insulation between the cold permafrost beneath the surface and the warm air above. As a result, considerably less thawing occurs in the meadow than on the ridges.

Throughout the Pen Island area are a variety of patterned ground formations. Field examination by trenching and probing was carried out to learn the nature of these features and their possible mode of creation.

On most of the ridges near the camp, there are large-scale unsorted polygons about 4 to 5 m in diameter with small ditches or cracks on each side. The presence of segregated ice in the ditches indicates that these are ice-wedge polygons, formed by the growth of massive ice in cracks caused by the thermal contraction of the ground in extreme cold.

Circular to elliptical hummocks up to 1 m in height are common throughout the sedge meadows in the treeless zone near the coast (Figure 3.3). Trenching revealed the existence of a dirty lens of segregated ice under each hummock, with mineral soil, thick peat and then moss over top. This type of feature originates as a thick clump of moss that raises the surface slightly and causes differential freezing. As a result, a lens of ice begins to develop under the clump, thereby raising the surface further and leading to continued differential freezing. The mass of ice enlarges and pushes up the surface until it cracks open, at which point warm air reaches the ice lens, melts it and causes the hummock to collapse. The cracking phase was observed on some of the larger hummocks at Pen Island.

Figure 3.3 Ice-covered hummocks in sedge meadows near the coast

Nonsorted circles, commonly known as mud circles or frost boils, are prevalent along the crests of the stream channels of the open tundra (Figure 3.4). Having a width of 30 to 60 cm, these slightly elevated features are vegetated on the sides but totally barren on the flat tops. They are composed of unsorted silty clay and occupy dry sites, the nearby rivers lowering the water table in these parts of the sedge meadow. Apparently they are the product of "cryostatic pressure", a mechanism that causes pockets of unfrozen soil to be forced up to the surface by the freezing and expansion of the soil around them.

The inland partially wooded area was examined in the field only in the vicinity of Mintiagan Creek (Figure 3.1), due to problems of access in areas away from the rivers. Along the Mintiagan, a series of thermokarst lakes is found just downstream of the first wooded sites (Figure 3.1). These are roughly circular and relatively deep pools with steep, only partially vegetated sides. They are generated when the subsurface permafrost melts in response to the warming effect of the river waters. The land surface collapses, thereby indicating the disappearance of perennially frozen ground at that site.

The continued existence of permafrost in the inland area is revealed by the presence of certain periglacial phenomena, notably peat plateaus and palsas. These are flat, slightly elevated and gregarious domed features, respectively, each having frozen material beneath which raises the surface. Their occurrence at Pen Island was generally observed during aircraft and helicopter overflights, although one peat plateau was traversed during the field season. Its surface was dry and hummocky, and, as in the case of most other peat plateaus, it was

Figure 3.4 Frost boils or unsorted circles along crests of stream channels near the coast

situated beside a river and was extensive, requiring measurement in terms of 10's of metres.

While not actually seen in the field, some of the peat plateaus have collapse areas in their central parts. They are visible on the aerial photographs (Figure 3.5) and are identical to those described and illustrated by Tarnocai (1974) in northern Manitoba. The scars are wet, roughly circular depressed areas which have fallen due to the melting of the permafrost beneath. They, like the thermokarst lakes, indicate the local disappearance of perennially frozen ground.

3.2.4 Fluvial Geomorphology

Fluvial processes at Pen Island produce considerable modification of the relic coastal environment. Near the coast, they remove material and increase the relief, and throughout the area they improve local drainage and initiate the development of new landscapes. General observations of the fluvial forms and processes at Pen Island were made during the field season. These included basic examinations of the drainage pattern, the stream channels and the nature of the water flow.

The drainage pattern is better studied on aerial photographs where it can be seen in plan, but a number of aspects of the network are also apparent at the ground level. The relic coastal landforms at Pen Island exert a strong control over the modern drainage system in the area. The beach ridges present major blockages to flow, causing channels to travel parallel to or even away from the coast for sizable distances. They result in an overall trellis type of drainage pattern. The relic saltmarshes are now low flat meadows, and their very gentle gradient induces meandering of the stream channels as they make their

Figure 3.5 Collapse scars located in central parts of peat plateaus (A)

way to the sea. The Mintiagan and its tributary that flows near the camp are good examples of the ridge and marsh effects upon the drainage network (Figure 3.6). As well as influencing channelized flow, the relic saltmarshes are partially responsible for the absence of an integrated drainage system in the modern meadows. Their lack of significant slope is important in causing excessive water to remain standing on the surface. At the same time, low areas between adjacent relic ridges often experience internal drainage and become long narrow lakes (Figure 3.6).

The nature of the drainage pattern at Pen Island plays a major role in making the area largely inaccessible in the summer months. Due to the presence of extensive, poorly-drained wetlands and numerous lakes over much of the surface, travel is better achieved by following the rivers than by taking an overland route. The stream channels, however, wander widely and flow along the coast as well as towards it, greatly increasing the distance to be travelled between two points.

The fluvial channels at Pen Island flow at moderate speed, but in some constricted areas there are small rapids. In the young treeless area near the coast, the streams generally occupy valleys with vegetated and moderately sloping sides 1.5 to 2 m high. This is the case with the Mintiagan and its tributary near the camp, as well as their smaller feeder streams. Further inland in the older wooded zone, the Mintiagan has developed small floodplains along its length. These are frequently traversed by many narrow rivulets which have cut relatively deep channels into the floodplain surfaces.

Figure 3.6 Influence of relic beach ridges and saltmarshes on drainage system at Pen Island

Factors contributing to the erosion of the stream channels at Pen Island include a continually increasing gradient as the land undergoes isostatic recovery, and excessive flow during the spring thaw and after large storms. Near the coast, evidence of undercutting suggests that high water produces lateral erosion of the channel banks. This is also apparently the case further inland, where the channels often have almost vertical sides. When flooding takes place in the older areas, the velocity of flow is rapidly decreased by the riverside vegetation, causing sediment deposition and floodplain buildup. A different situation exists in the younger treeless zone, where the more rapid runoff has created relatively large and deep valleys that are capable of containing the excessive flow most of the time.

Finally, the field season at Pen Island revealed the great variability of the water level in the fluvial channels. The storm of August 26 caused the water in the tributary near the camp to rapidly rise by at least 1 m. Following the storm, it dropped nearly .6 m between the morning and early evening. This typical situation is the result of several aspects of the hydrology in this area of continuous permafrost. First, the presence of permafrost everywhere concentrates rain- or melt-water near the surface and prevents deep seepage. Second, the existence of only low vegetation and no trees near the coast produces a rapid rate of surface runoff. These two factors together create a lack of sufficient storage mechanisms for heavy rains and thaws. As a result, there is a large volume of water available to the streams at one time, and once it is gone, the streams can only be recharged by previously existing water reserves.

3.3 Remote Sensing Investigations

The second aspect of the field work at Pen Island involved observing the various landscapes in terms of their landform,vegetation type, drainage conditions, parent material and depth of peat. Prior to going into the field, an aerial photographic enlargement of the area was examined and areas of different image characteristics were delineated. A route was selected to allow all accessible areas to be studied. Two trips were necessary, one to cover the young, treeless terrain near the coast, the other to cover the older wooded area further inland (Figure 3.7).

3.3.1 Young Landscapes

Investigation of the young terrain was carried out by following a prescribed route, observing and photographing various aspects of the land. As the base camp is located in this area, observations were also made on other excursions, in order to become familiar with the variations in each category of landscape.

a) Site 1 is an area of wind-blown sand. It consists of dunes and blowouts, and has considerable relief. The height of the land and the sand- and gravel-sized material result in excellent drainage at Site 1, and the ground is very dry. Direct exposure to the strong onshore winds makes the area unstable, resulting in a barren or only partially vegetated surface. The active beach to the east of the camp is similar, but its general lack of vegetation is due to its extremely young age as much as its instability. In both areas, the first plant colonizer appears in small, isolated clusters and is

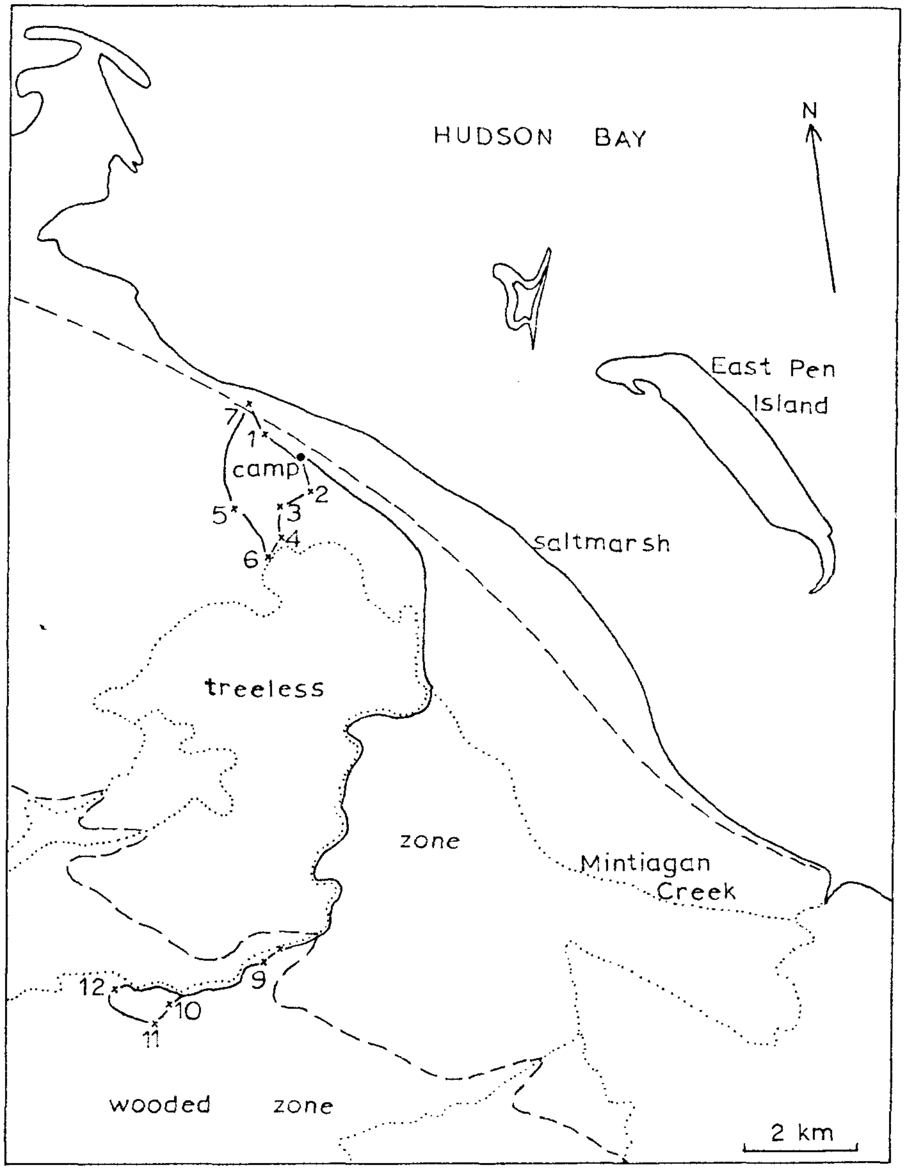


Figure 3.7 The location of field investigations of landscape types at Pen Island. Numbers refer to descriptions in text.

Elymus arenarius, a xerophytic grass-like plant (Figure 3.8).

b) Site 2 identifies the lichen heath landscape of the recently fossilized beach ridges. The ridge on which the site is located is typically narrow (about 100-150 m) in width and low (1 m) in relief. Prevalent across its top are the erosional arcs described in a preceding section. They are found only on the leading ridges and are not apparent on those just slightly inland. Pits dug at several locations were similar to the one at Site 2, where the parent material was sand and the peat layer was very thin (1 to 2 cm). The sand in each pit was relatively dry, owing to the large grain size and the elevated position of the ridges. As illustrated in Figure 3.9, this area has a continuous mat of vegetation, primarily being composed of various species of lichens but also including a number of vascular plants. On the leading ridge, the lichen species are less plentiful than on the other ridges which are slightly older and less exposed (Kershaw and Rouse, 1973). At its eastern end, which is younger again, the lichens disappear completely.

c) Site 3 is a freshwater wetland termed a sedge meadow by the biologists working at Pen Island. It is a fen, a peaty area whose water table is generally at the surface. The Pen Island sedge meadows are low areas that frequently have standing water from a few centimetres to a metre or more in depth. Throughout are numerous ice-cored hummocks whose formation is initiated by the growth of certain mosses, as previously explained. Samples of the parent material were collected at Site 3 and at many other locations,

Figure 3.8 Sand beach ridge with isolated *Elymus arenarius* (Site 1)

Figure 3.9 Lichen heath landscape (Site 2)

including atop the hummocks, and all were clay or silty-clay. Peat accumulations ranged from 6 cm in the flat areas to as much as 50 cm on some of the larger hummocks. Drainage in this area is very poor, except for the hummocks, which are fairly dry. In general, the vegetation in the sedge meadows consists of sedges (*Carex* sp.) and grasses that grow above the height of the water (Figure 3.10). At Site 3, the hummocks are covered with lichens and mosses, but further inland where the hummocks are better developed, there are also willow (*Salix* sp.) and swamp birch (*Betula glandulosa*) up to a height of 45 to 50 cm.

d) Site 4, labelled a peat meadow by this investigator, is also a freshwater wetland that is covered by peat. Its water table is high but is not at the surface. As a result, the land is slightly elevated and lacks standing water, and it is a bog rather than a fen. The general surface at Site 4 and throughout the peat meadow is uneven, consisting of tightly-packed tussocks of moss. In lower marginal areas, it blends with some features of the sedge meadow and forms a transitional zone. Generally, however, the slightly elevated surface of the peat meadow results in drier conditions and the aquatic sedges and grasses disappear. Instead, the vegetation cover includes lichens and many mosses, along with some low willow and an assortment of other vascular plants (Figure 3.11). Pits at three locations revealed the peat depth under the vegetation mat to be 10 to 20 cm and the parent material to be clay or silty clay. Site 4 and other areas of peat meadow tend to be broadly adjacent to the stream

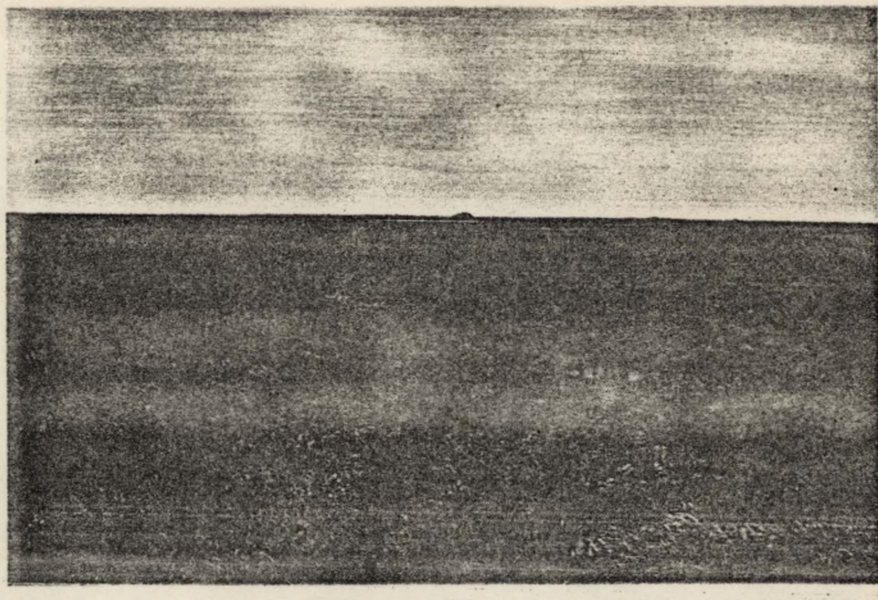


Figure 3.10 Sedge meadow with aquatic vegetation and standing water (Site 3)

Figure 3.11 Peat meadow (Site 4)

channels, whereas the sedge meadows are more removed. Apparently the lowered water table in the vicinity of the creeks is significant in the development of the peat meadows. It is suggested that these landscapes are in fact peat plateaus whose formation is due to the growth of ice lenses in the frozen ground.

e) Site 5 is a variation of the sedge meadow (Site 3) that is differentiated by its wetness. The surface water is considerably more than a metre deep in this area, and there are few or no hummocks present. The vegetation, which is totally aquatic and consists of sedges and grasses, generally emerges from the water,but in some areas it does not. Figure 3.12 shows typical areas of very wet sedge meadow.

f) Site 6 represents a landscape of small areal extent at Pen Island. Located immediately beside the stream at the base of the valley sides, it is an area of wet clay and silty-clay material upon which there is a growth of grasses and willow (*Salix*) shrubs less than a metre high. Frequently, 1- to 2-metre sections of the banks have slipped into the stream, leaving bare scars on their upslope sides (Figure 3.13). Site 6 is subject to flooding from time to time over the ice-free season as the water level fluctuates.

g) The last landscape examined in the area near the coast was observed from a remote location only. Site 7, the modern saltmarsh, can readily be seen from the leading ridge, which stands some 2 m above its surface, and also from the large dune, which is another 15 m higher.

Figure 3.12 Wet sedge meadow with totally aquatic vegetation, viewed from drier margin (Site 5)

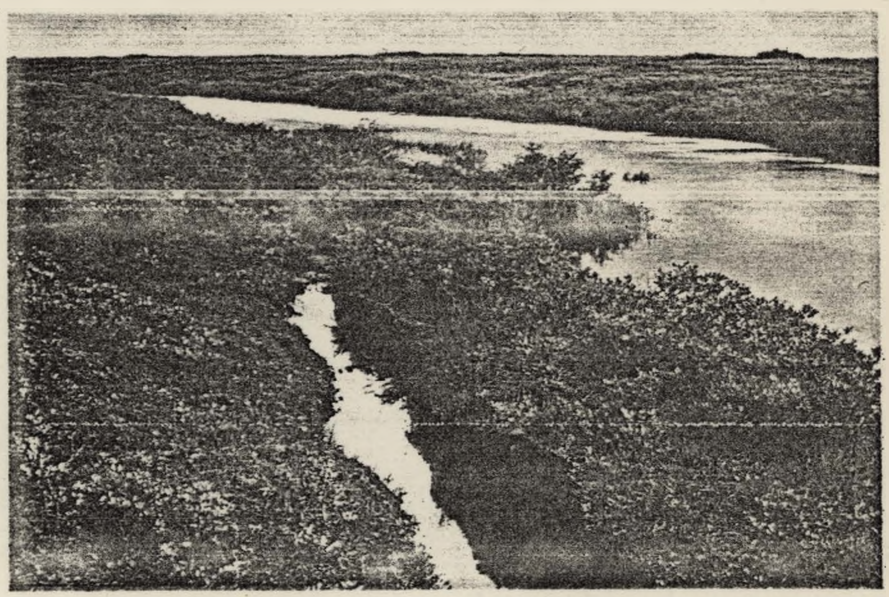


Figure 3.13 Riverside grasses and low willows with slide scars (Site 6)

The view is illustrated in Figure 3.14. The 3 zones in the saltmarsh, described at length by Kershaw (1975) and reviewed in the preceding chapter, are readily apparent in this image.

3.3.2 Older Landscapes

Further inland where trees begin to appear, a number of different landscapes are present. Due to the extensive wetlands throughout the Pen Island area, these could in practical terms only be reached by travelling up the rivers and then venturing overland for short distances.

a) Site 8 typifies the floodplain of the Mintiagan south of the tree limit and is well portrayed in Figure 3.15. A gently sloping surface usually 10 to 20 m in width, this landscape is relatively well drained and has very little accumulation of peat. It is composed of coarse sandy material with large cobbles often resting on the surface, suggesting accretion during times of high stream energy. Covering the ground in some areas is a mat of grass-like vegetation, while in other areas there are thickets of willow (*Salix*) and birch (*Betula glandulosa*) which grow up to 2 m tall (Figure 3.16).

b) Site 9 situated adjacent to the floodplain, is a spruce forest (Figure 3.17). It is the first significant tree growth reached as one travels upstream from the coast. Primarily consisting of black spruce (*Picea mariana*) but also including some tamarack *(Larix laricina)*, the forest generally has a closed grown. As a result, little direct sunlight reaches the forest floor with its cover of mosses and a few

Figure 3.14 Vegetation zonation in the saltmarsh (Site 7)

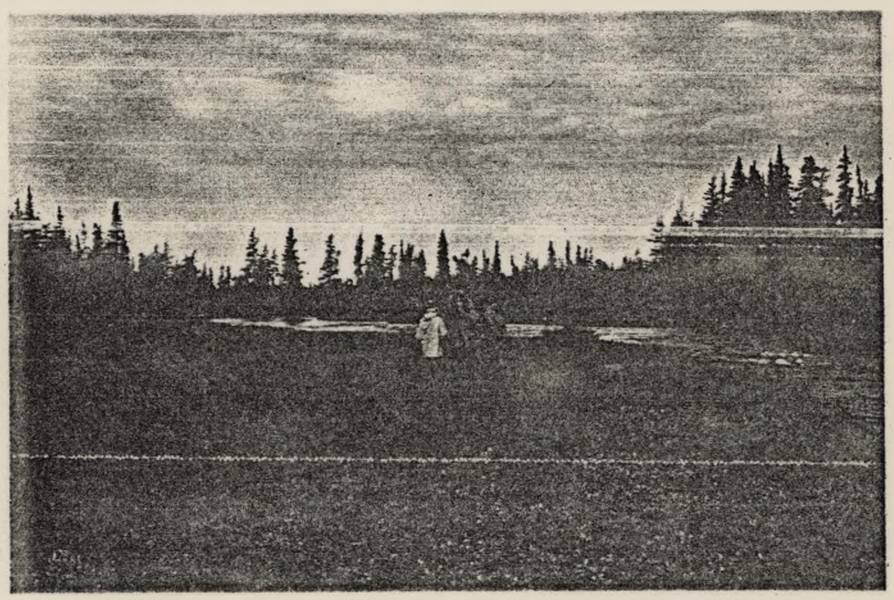


Figure 3.15 Floodplain of Mintiagan Creek in wooded zone (Site 8)

Figure 3.16 Willow-birch thickets along Mintiagan Creek in wooded zone (Site 8)

Figure 3.17 Spruce forest adjacent to Mintiagan Creek (Site 9)

lichens. The ground is uneven and spongy underfoot, as there are thick accumulations of peat moss. Although the surface is generally dry,the area is poorly drained. The peat holds much water, and the moist conditions are attested to by the presence of fungi, especially mushrooms. Water exceeding the capacity of the peat is removed from the area by many small winding creeks about 1 to 2 m wide.

c) Site 10 identifies the older sedge meadow where the water is less than a metre deep. It differs from the sedge meadow near the coast (Site 3) mainly in terms of its vegetation. Although the sedges and grasses of the younger meadow are still present, there is also a thick growth of shrubbery projecting about .75 m above the water surface and consisting of willow (*Salix* sp.) and swamp birch (*Betula glanulosa*) (Figure 3.18). There are also some larger conifers, chiefly tamarack (*Larix laricina*), which are about 4 or 5 m high in most cases. Walking through this landscape disturbs the silty sediments and throws the fine material into suspension.

d) Site 11 is representative of the spruce-lichen woodland. Located on a relic beach ridge about 2 m or more higher than the adjacent sedge meadow, it is a well drained site. Pulling back the lichen mat revealed very little peat accumulation and sandy material. The vegetation at this site includes an open woodland of black spruce (*Picea mariana*), the trees being tall and well developed as they are in the spruce forest (Site 9). The ground is covered with a carpet of almost pure *Cladonia alpestris* lichen, which is often 25 cm thick (Figure 3.19). The widely spaced trees allow this pale green-gray

Figure 3.18 Shrub-covered sedge meadow in wooded zone (Site 10)

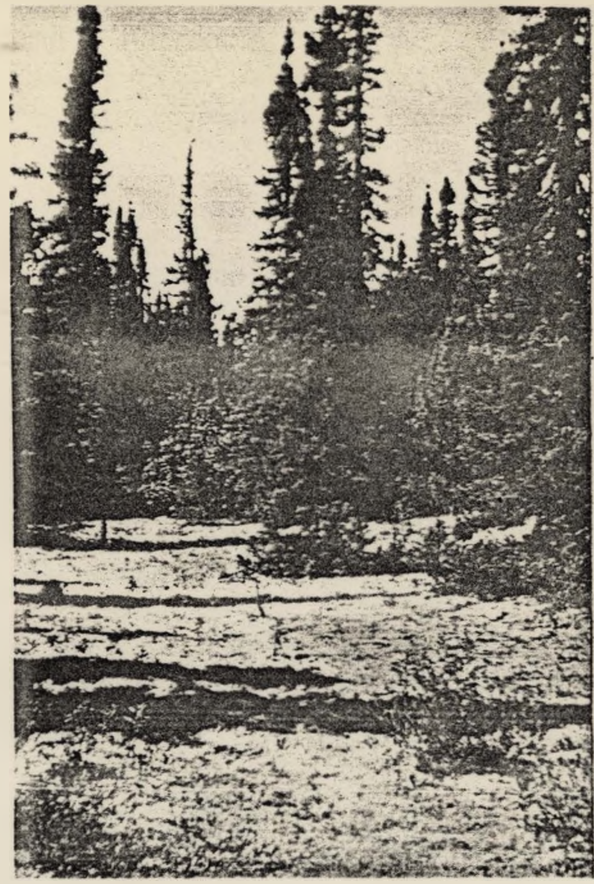


Figure 3.19(a) Spruce-lichen woodland (Site 11)

Figure 3.19(b) Close-up of lichen mat in spruce-lichen woodland (Site 11)

mat of vegetation to be open to the sky.

e) Site 12, a peat plateau, is elevated about 1 to 2 m above the height of the sedge meadow. As with the peat meadow near the coast, this area is located near the river and is well drained. The surface is uneven and very compressible, indicating the presence of a thick layer of peat. Like the spruce forest (Site 9), this area has a tree cover of *Picea mariana* and a ground cover of mosses and some lichens. It differs, however, in that the crowns are somewhat more widely spaced and the lichens are more common. These are rarely *Cladonia alpestris*, and visually they blend in with the mosses. No surface water is visible at this site, unlike the spruce forest which is crossed by many small streams. Unfortunately, photographic difficulties were encountered at this stage of the journey and no images of the peat plateau are available.

f) Finally, Site 13 exemplifies the palsa bogs located some 25 km inland from the coast. Due to its distance from the camp, this wetland landscape could not be examined at the ground level. Photographs were taken during the aircraft flight into the area, and one of these is reproduced as Figure 3.20. The palsa is a circular to elliptical area whose surface is raised by a frozen core that contains many lenses of ice. At Pen Island, it is covered primarily with *Cladonia alpestris* lichen and therefore appears as a grey-green colour on conventional colour film. Palsas tend to occur in groups, separated from each other by fens. The latter are depressed areas which may contain standing water and generally support a vegetation cover of

Figure 3.20 Palsa field with lichen-covered palsas and sedge-.or water-covered fens. (Site 13)

mosses and aquatic plants.

3.4 Summary and Conclusions

In summary, field investigations at Pen Island were carried out to provide a body of information that would be helpful in the analysis of landscapes by remote sensing techniques. Part of the work was devoted to the study of geomorphological forms and processes, since this type of information was not available for the area. The other part involved the examination of landscape types as integrated units of many natural phenomena. The studies were carried out with their ultimate use as ground truth in mind. As a result, the geomorphological observations are solely descriptive and the landscape observations are relatively basic.

Due to isostatic recovery of the earth's crust in the vicinity of Hudson Bay, the Pen Island area has, in effect, been experiencing a marine regression since its time of deglaciation, when it was completely submerged. In consequence, the most important factor in the genesis of landforms at Pen Island has been the coastal geomorphology. The landscape is essentially one of active and relic coastal phenomena.

The modern shoreline at Pen Island is characterized by sand and gravel storm ridges, created during stormy weather by high-energy waves and surging waters, with lagoons and saltmarshes on their leeward sides. When these features become fossilized as the land continues to rise, the ridges become dry upland sites and the lagoons or marshes become freshwater wetlands. Both undergo modification by a number of non-coastal geomorphic processes. The young ridges are worked by the wind and develop dunes, blowouts and other smaller features. More widespread are periglacial and fluvial types of activities.

Periglacial processes take place throughout the Pen Island area, which is underlain by continuous permafrost. Particularly common is the growth of massive or segregated ice, a process which leads to the formation of a variety of small- and large-scale features. These range from ice-cored hummocks and ice-wedge polygons to peat plateaus and palsas. The presence of perennially frozen ground at Pen Island concentrates rain- and meltwater in a thin active layer. This abundant supply of water is considered to be important in the development of the massive ice features. Combined with the flatness of the relic saltmarshes, it also is significant in the maintenance of the extensive freshwater wetlands.

There exist certain periglacial landforms at Pen Island that imply the localized disappearance of permafrost. Generally located from 15 to 30 km inland but sometimes occurring only 6 km from the coast, these features include thermokarst lakes along some of the rivers and collapse scars in some of the peat plateaus. While no definitive conclusions can be made without detailed field examination, it is possible that the southern limit of continuous permafrost in this area may lie a few 10's of kilometres closer to the coast than Brown (1967, 1968) anticipated.

Processes of fluvial geomorphology at Pen Island affect and are affected by relic coastal environment. The streams remove material from the ridges and marshes and deposit it in other locations.

They also improve the drainage of the land adjacent to their channels. In each case, new landforms are created. While the actual channels modify the relic coastal phenomena, the pattern which they create over the landscape is largely controlled by those same fossil features. The presence of the ridges and marshes produces a series of meandering channels that are integrated into a trellis type of drainage network.

Biophysical units were examined in the young treeless and the older wooded areas of the Pen Island landscape. They have been described in terms of their geomorphology, parent material, drainage conditions, peat depth and vegetation, and photographs of each unit have been presented. In general, all of the sites located on the relic beach ridges are well drained, as they are elevated above the general level of the terrain and they are composed of sandy material. They are similar in that they have little accumulation of peat, but they differ in the nature of their vegetation cover. The wetland sites situated in the low-lying relic saltmarshes have finer, silty parent material and greater peat accumulation than the ridge sites. Some parts of the wetlands, raised by frozen ice cores and relatively well drained, are bogs. Other parts often have standing water on their surfaces and are fens. As with the ridge sites, the bogs and fens each contain a number of landscapes that are differentiated by their type of vegetation.

If the three zones in the modern saltmarsh are included, 15 different landscapes were studied at Pen Island during the field season. Variations were apparent within each of these, and sometimes there were transitional areas between adjacent landscapes. These factors are expected to cause some difficulties in the remote sensing investigations, especially when digital techniques of analysis are employed.

Only two landscapes known to be in the Pen Island area were not examined in the field. These include the old and new burns, both of which are located a considerable distance inland and cannot be reached by a day's travel from the camp. Fortunately, these landscapes have been studied elsewhere in the Hudson Bay Lowlands by Rouse and Kershaw (1971), whose descriptions have been presented in the preceding chapter.

CHAPTER IV

INTERPRETATION OF AERIAL PHOTOGRAPHY

4.1 Introduction

The field investigations at Pen Island have produced a set of landscape information pertaining to point locations only. In order to translate this knowledge into a spatial context, remote sensing techniques should be employed. This is especially the case in a wetland environment like Pen Island, where access for field work is very restricted from a practical point of view.

While a number of types of remote sensing data are available, aerial photography is the only one whose capabilities for environmental analysis are generally established. As a result, the Pen Island landscape is initially examined by airphoto interpretation techniques. This work provides "ground truth" for the analysis of satellite data, and also permits the investigator to learn the nature of the landscapes in the area and their spatial relationships among one another.

Based on the literature review of remote sensing in the sub-arctic, as well as the experiences of this writer in other regions, colour infrared aerial photography is the best overall means of air-craft remote sensing for the study of the environment. This type of data had already been obtained for the Pen Island area in the summer of 1973. While it precedes this investigation by two years, the time difference is not critical in this wildland area where the growth of vegetation is very slow and the relief is very subdued.

It is important that the nature of the remote sensing data be understood before its interpretation is carried out. The user must realize what type of information has been recorded by the sensing device. Hence, the various aspects of the colour infrared aerial photography employed in this thesis are reviewed. Subsequent portions of this chapter describe and discuss the procedure followed and the results obtained in the analysis of this data for the Pen Island area of northwestern Ontario.

4.2 The Aerial Photography

The aerial photography used in this thesis was obtained with Kodak Ektachrome Infrared Aero film, Type 2443. Developed by Kodak specifically for aerial photographic missions,this film is sensitive to the visible wavelengths of radiation (from 0.36 to 0.7 μm) as well as the near-infrared wavelengths (from 0.7 to 0.9 μm). The near-infrared sensitivity of Film 2443 makes it especially suitable for the detection of variations in vegetation. It is in this band that plants show their greatest variation in radiation reflectance.

The colour film is composed of three emulsion layers, each containing silver halide particles sensitized to a different portion of the electromagnetic spectrum. With the colour infrared type, the emulsions are sensitive to the green, red and infrared wavelengths. All three of the layers have an inherent sensitivity to blue light, but these undesirable wavelengths can be prevented from reaching the film by placing a filter in front of the camera lens. In the photography employed in this investigation, a Wratten No. 15 (deep yellow) filter was used to absorb all incident radiation below 0.52 μm. This elimination is important, since it is the shorter visible wavelengths that cause haziness on the photographic image.

Processing of the colour infrared film yields colour positive photographs. Each emulsion in the film is assigned a differently coloured dye, as is described in Table 4.I. When the film is developed, the dyes in effect subtract their complementary colours from white light in order to produce a coloured image (Table 4.I). The amount of dye removed from each emulsion is inversely proportional to its degree of exposure. If the exposure is great, then little colour will be removed, but if the exposure is weak, then much more colour will be removed. The actual colour perceived by the human eye at any point on the final scene depends on the relative exposure of each emulsion layer at that point. This, in turn, depends mainly on the dominant wavelengths of radiation reflected from the earth's surface (Table 4.I). Vegetation, for example, has its greatest reflectance in the near-infrared band. When it is photographed with colour infrared film, the infrared-sensitive emulsion is highly exposed and the red and green emulsions are poorly exposed by comparison. As a result, the dyes in the red and green layers are well developed,removing much green and blue light from the white light of the final scene. Only the red light of the poorly developed infrared layer is left to show through. The photo interpreter, therefore, observes red-coloured vegetation.

TABLE 4.I

PRINCIPLES OF OPERATION

FOR INFRARED-SENSITIVE COLOUR FILM

Dominant radiation reflected from object	Blue	Green	Red	Infrared
Film sensitivity with Wratten Number 15 Deep Yellow filter	--	Green	Red	Infrared
Dye associated with each emulsion layer	--	Yellow	Magenta	Cyan
Photographic colour of object	Black	Blue	Green	Red

Images recorded on film may be produced as prints on photographic paper or as transparencies on clear film. The transparency is the preferred base for airphoto interpretation, since the image quality is superior to that obtained on paper. With the print, the graininess of the paper used in the reproduction process reduces the spatial resolution of the image, thereby reducing the amount of information available to the user.

The flying of the Pen Island photography was carried out at a height of 6100 m above sea level with a superwide angle lens of focal length 86.4 mm. Although the flying height was not a high altitude one, the use of the short lens resulted in photography at a nominal scale of 1:70,000. This is a simulated high altitude photographic platform. Because it yields images at a small scale, the number of photographs required to cover a given area is reduced, and each one gives a synoptic or regional view. The use of the superwide angle lens, however, causes a distinct illumination fall-off from the centre of the imaging plane to the edges. This produces photographs whose corners are considerably darker than the centre. Termed image density distortion, the problem is in large part related to the optics of the camera system. It can be reduced substantially by the use of an antivignetting filter, a device which limits the illumination reaching the centre of the imaging plane, in order to make it correspond more closely with that reaching the marginal areas. In the case of the Pen Island photography, a 3.3X antivignetting filter was placed in front of the lens.

4.3 Procedure

Careful thought must be given to the selection of a site for the photographic study of landscapes at Pen Island, as the results must later serve as "ground truth" for the analysis of the LANDSAT data. The chosen site must include all land types in the area of interest, and also must include some reference features, such as lakes, that will be recognizable on the satellite images. At the same time, it should cover all of the area examined in the field investigations. The site selected for study is illustrated in Figure 4.1. It is elongated in a southerly direction, in order to include the young treeless zone near the coast and the older wooded environment further inland. Its inland limit marks the point where all nearshore landscapes have evolved into inland types and where no further change is apparent on the colour infrared coverage to the south.

Before interpretation of the aerial photography can be started, a base map must be obtained and a classification scheme devised. For the Pen Island area, the largest scale of topographic map available is the 1:250,000 one, which is too small for the purposes of this investigation. As a result, it was decided that a "map" should be constructed from the colour infrared photographs at a scale of approximately 1:70,000. The "map" would not have accurate distances, due to the relief displacement that arises in the photography of a natural surface. (This term refers to the distortion in scale with distance from the centre of the image that is caused by variations in the relief of the land surface.) It would, however, be sufficiently precise for the landscape analysis. Using adjacent photographs, the

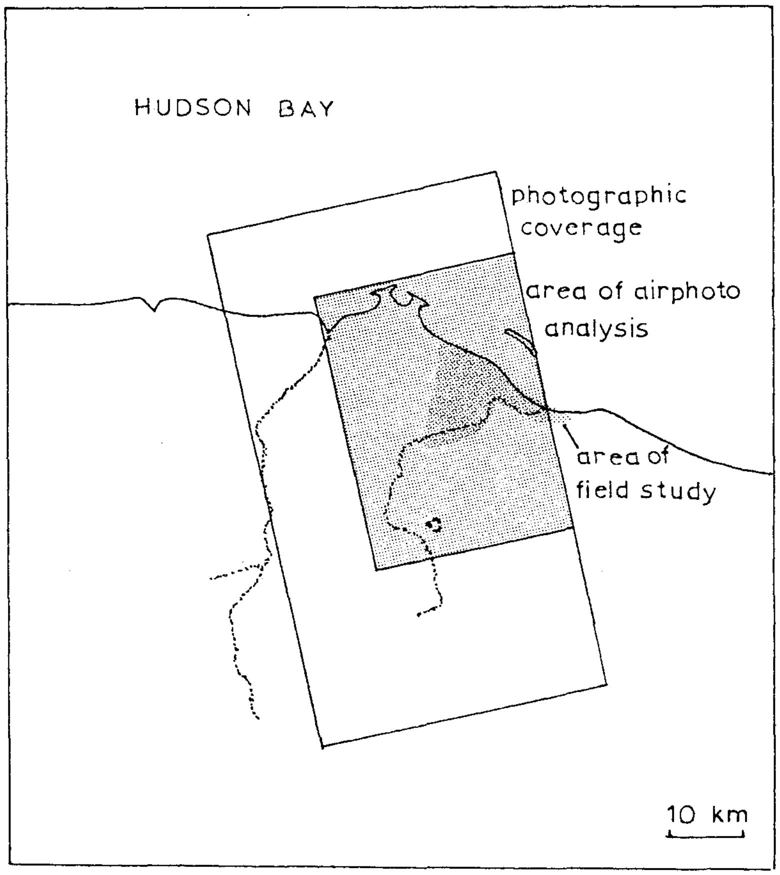


Figure 4.1 Site selected for airphoto interpretation

map base was produced by tracing the major lakes and river networks onto a paper overlay. Only the central portions of the images were used, in order to minimize the relief distortion. This factor was considerable even though the land surface at Pen Island has very little relief, since a lens of short focal length (86.4 mm) had been employed in the photographic mission.

The derivation of a suitable classification system for the Pen Island area involved a consideration of previous readings of landscape analyses and plant biology, of field investigations at the site, and of a preliminary examination of the photography. The scheme devised initially was tested and found to be unsatisfactory, whereby it was revised and tested a number of times further until a suitable one was found. The final classification system is presented in Table 4.II. Descriptions of each class have already appeared in Sections 2.4 and 3.3.

Although the classification scheme developed for the Pen Island area is a biophysical one involving many aspects of the environment, the classes have generally been named according to their vegetation type. The reason for this approach is two-fold. First, the field familiarization was carried out in conjunction with plant ecologists, and their terminology took on biophysical meaning for this writer. Second and more important, the vegetation is directly visible on the photography. If, for example, a class is referred to as a "spruce woodland", then its photo image must show an open crown of coniferous trees. An area with no trees or with a closed forest cannot fit into this category of landscape.

TABLE 4.II

CLASSIFICATION SCHEME FOR PEN ISLAND

1	Upland Sites	10	Relic Ridges	101	Bare Sand
				102	Lichen Heath
				103	Spruce-Lichen Woodland
				104	Recent Burn of 103
				105	Old Burn of 103
2	Wetland Sites	20	Saltwater Wetland	201	Tidal Flats
				202	Young Saltmarsh
				203	Mature Saltmarsh
				204	Transitional Marsh
		21	Freshwater Wetland	211	Peat Meadow (Bog)
				212	Sedge Meadow (Fen)
				213	Wooded Peat Plateau
				214	Spruce Forest
				215	Palsa Bog
				216	Recent Burn of 213
		22	Riverine Wetland	221	Grasses and Short Shrubs
				222	Grasses and Tall Shrubs

The Pen Island classification system is similar, but not identical, to the generalized scheme of Lacate (1969) already described in Chapter II. Table 4.III defines specific classes at the two finer levels of the Lacate system. Derived from the report of Thie (1976) for northeastern Manitoba, it provides a basis for the comparison of the two classification schemes.

Examining the Pen Island and Lacate systems together reveals that each is a hierarchical classification suited to the biophysical analysis of the Hudson Bay Lowlands. The Lacate system also includes two more general levels, but these have not been presented for comparison, as the Pen Island project lacks the areal extent of the Manitoba work. The basic unit of each classification scheme is the same. It is an area which has a relatively homogeneous combination of soil type and vegetation. While the Pen Island one does not actually define the type of soil, it conveys similar information by describing the peat accumulation and parent material for each class. The primary difference between the two systems lies in the method by which they order the landscape. Whereas the Lacate approach groups together a number of recurring land types to create a land system, this one groups together land types of similar physiography. This is done chiefly to organize the many land types into a more readily understood scheme. It does not replace the land system, which is mapped a smaller scale (1:125,000 to 1:250,000). Rather, it is a supplement to it, portrayed at a scale of 1:70,000 to 1:100,000 and designed for improved comprehension of the more complicated map of land types.

TABLE 4.III

APPLICATION OF THE LACATE CLASSIFICATION SYSTEM TO NORTHERN MANITOBA

(A Selection of Classes from Thie, 1976)

Land Type	Comparative Class (Pen Island)	Land System
B1 Sedge fen	212	F2-I
B2 Patterned sedge fen	212	
B3 Sedge fen, some tamarack	212	F2-I-P1
C1 Tamarack-sedge fen	212	P1-B1
C2 Shrub-covered sedge fen	212	
		B1-B3-G1
D1 Spruce forest, moss ground cover	214	
D2 Spruce-tamarack forest	214	01-D3
D3 Spruce forest, taller than D1	214	
		E3-C1-G2
E3 Sedge fen with palsas	215	
		E1-B2
F1 Willow-birch along rivers	221,222	
F2 Saltmarsh	202,203	G1-C2
G1 Treeless peat plateau,moss-lichen cover	211	E1
G2 Wooded peat plateau	213	
		F1-B1
I Mudflat	201	
		F1-D2-G2
01 Spruce-lichen woodland on dry till	103	
02 Spruce-lichen woodland on moist till	103	C1
P1 Sandy Beach,dry,lichen or bare surface	101,102	D2-C2
P2 Sandy Beach,moist,lichen surface	102	

Having tested the suitability of the base map and the classification system for the Pen Island area, the process of airphoto analysis was begun following standard interpretation procedure. This involved using image characteristics, field data and background knowledge to recognize the different categories of landscape on transparencies of the colour infrared aerial photography. The physiographic classes were delineated on the map base and were then subdivided to give land types.

As the interpretation was being carried out, it readily became apparent that the complexities of and variations in the photo patterns were highly confusing and visually overwhelming. To ease the interpretation process, several modifications of the initial procedure were introduced. First, to better understand the nature and distribution of the different types of vegetation in the area, a number of basic biological texts were consulted. These provided more information on the characteristics of the many plant groups and their environmental associations. Also examined were published spectral signatures for the various plant types, in order to gain some idea of the sort of image that each would produce. These are reproduced in Figure 4.2. Second, to organize the landscapes at Pen Island and reduce the confusion, a map of the physiographic units was initially constructed, and then a separate map of the more detailed land types was produced. Each class of the first map was subdivided individually so as to decrease the number of images to be considered at one time. Third, paper strips were used to block out the portions of each photograph not employed in the interpretation. By removing the marginal areas,

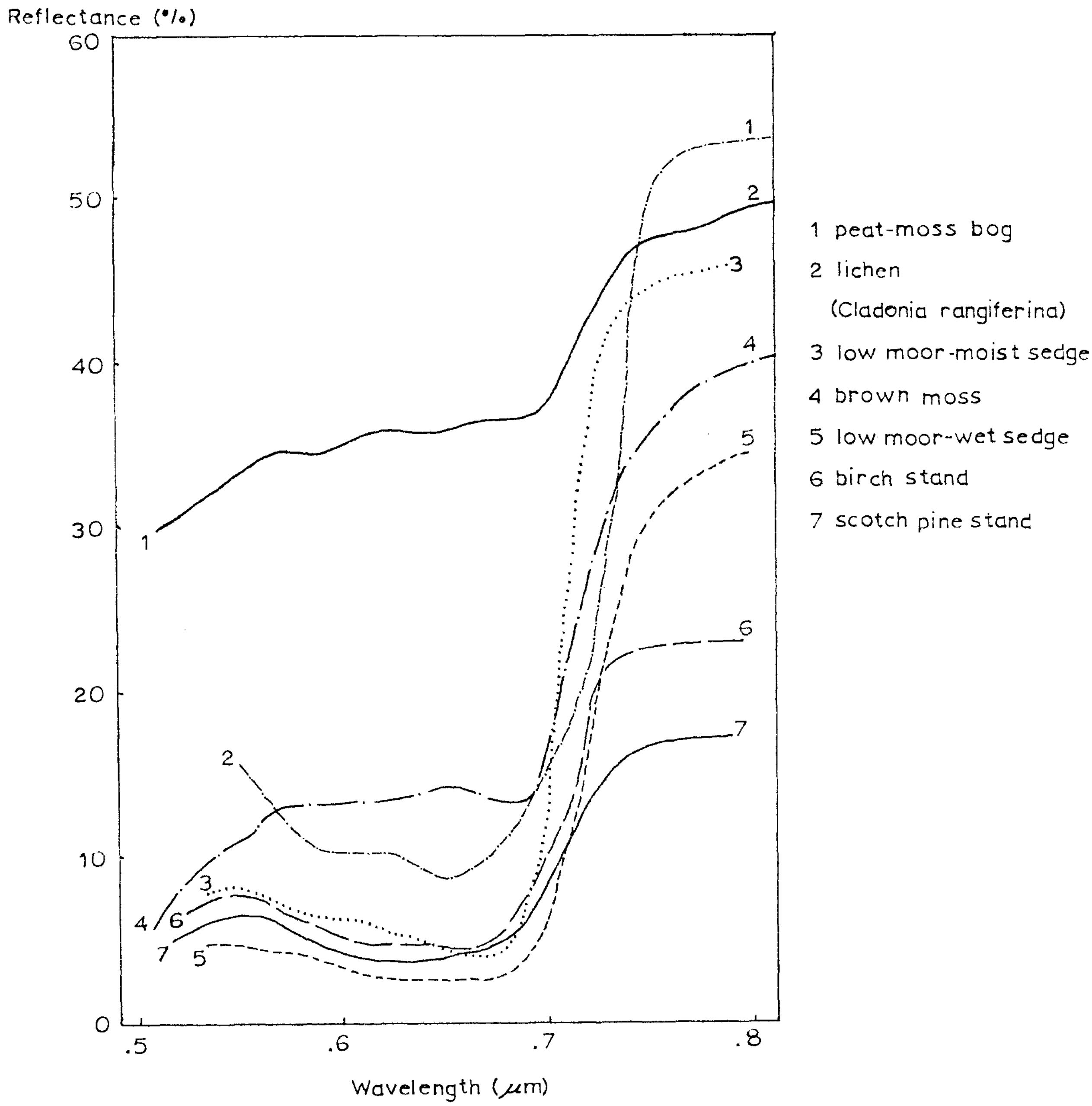


Figure 4.2 Spectral signatures of various plant surfaces (from Steiner and Gutermann, 1966)

the problem of distorted image density within a single class was minimized. Finally, due to the variability of images of a single class and the similarity among several classes, a system of visual and textual keys was devised. The former involved keeping handy the images and their interpretations for the area examined during the field season. The latter involved a written description of any distinctive image characteristics for each class, as well as the way in which two similar classes could be distinguished. These keys were not complete descriptions for the classes and have not been included here. They have, however, been incorporated into the following section which outlines the results of the interpretation.

4.4 Results

The completed airphoto analysis of the landscape at Pen Island is included in the pocket at the back of the thesis. Map insert 1 is a duplication of the map of physiographic or general landscape types. Map 2 (back pocket) portrays the more detailed interpretation of land types. Selected from Map 2 and presented in this chapter are representative areas of the Pen Island landscape. Figures 4.3 and 4.4 are the aerial photograph and its interpretation for a portion of the young treeless environment near the coast, while Figures 4.5 and 4.6 are the photograph and its interpretation for a portion of the older partially wooded environment further inland.

The criteria used to identify the different land types on the colour infrared photography of Pen Island are numerous. They are best described in tabular format, which allows easy comprehension and

Figure 4.3 Colour infrared aerial photograph of treeless zone near the coast of Pen Island. Scale 1:70,000.

Figure 4.4 Interpretation of area displayed in Figure 4.3 at 1:70,000 scale. For legend see Table 4.II.

Figure 4.5 Colour infrared aerial photograph of wooded zone at Pen Island. Scale 1:70,000.

Figure 4.6 Interpretation of area displayed in Figure 4.5 at 1:70,000 scale. For legend see Table 4.II.

interclass comparison. Presented in Table 4.IV are the image characteristics for the many landscape types at Pen Island.

4.5 Discussion

4.5.1 Procedure

The revised procedure employed in the biophysical analysis of the Pen Island aerial photography gave excellent results, and is considered to be highly suited for use in areas of similar complexity. A number of aspects of the interpretation methodology warrant further mention.

The production of a basic physiographic map and then a separate, more specific landscape map was most beneficial in the Pen Island study. The generalized map provided a tidy framework within which the landscape could be studied in detail. As each physiographic class was subdivided individually, the great variety of images and land types was not as overwhelming as if all classes had been examined together.

Also of value in reducing the confusion among the many images were the visual and textual keys. By describing only distinguishing characteristics and excluding any unnecessary details, these served as a concise data source for the differentiation of the classes, many of which were similar. The illustrations of the visual key were readily available for comparison, and were especially useful in the classification of boundary areas that included parts of two classes.

The paper strips placed over the outer portions of each aerial photograph were a rather simple but very helpful aspect of the

TABLE 4.IV

PHOTOINTERPRETATION CRITERIA USED TO IDENTIFY LANDSCAPE TYPES

Landscape Type	Hue	Tone (Chroma)	Texture	Shape	Pattern	Site
101	blue-white	very light	smooth	narrow linear	recurving ends, sub-parallel groupings	parallel to coast, near coast
102	grey	light to medium	smooth	narrow linear	fanning ends, sub-parallel groupings	parallel to coast, further inland than 101
103	white with brown-blue	light and dark	salt-and-pepper	narrow linear	fanning ends, often sub-parallel groups	parallel to coast, further inland than 102
104	blue	medium-dark	medium-smooth	broadly linear	some fanning ends and sub-parallel groups	parallel to coast, contiguous with 103
105	grey-pink	light	medium-smooth	broadly linear	some fanning ends and sub-parallel groups	parallel to coast, contiguous with 103, 104
201	blue-grey	light to medium	smooth to medium	--	--	adjacent to sea
202	red-peach	medium-light	medium to medium-coarse	elongate	highly indented seaward side, many ponds	on inland side of 201

Continued...

Table 4.IV Cont'd...

Landscape Type	Hue	Tone (Chroma)
203	red	medium-dark
204	red-grey	medium-light
211	pink	light
212	red to blue-brown-grey	medium-light to medium-dark
213	blue-brown and pink-white	medium-dark and light
214	red-brown	dark
215	white or red and grey-brown	light and dark

Texture	Shape	Pattern	Site
medium	elongate	--	on inland side of 202
medium-smooth	elongate	--	on inland side of 203
medium-smooth	--	--	adjacent to rivers, between coast and wooded zone
medium	--	--	between ridges (102) adjacent to 211 but away from rivers
medium	elongate with cuspate edge	bead-like strings often with light centres	especially along rivers, further inland than 211
medium	sometimes linear	--	along rivers and adjacent to ridges (103)
coarse	--	light ellipses in dark base	away from rivers and ridges (103) further inland than 211, 212

Continued...

Table 4.IV Cont'd...

Landscape Type	Hue	Tone (Chroma)	Texture	Shape	Pattern	Site
216	blue	medium-dark	medium-smooth	cuspate edges	bead-like strings	along rivers often, contiguous with 213
221	red	medium	smooth	--	--	adjacent to rivers near coast
222	red	dark	medium "tree" texture	--	--	adjacent to rivers within wooded zone, may obscure river channel

interpretation process. These eliminated the areas where image density distortion was substantial, reducing the number of different images apparent at one time and also preventing the incorrect identification of marginal sites through the use of the keys developed for the central parts of the photographs.

Lastly, since the Pen Island area has many surfaces covered by low-order plants, most of which this writer had not previously experienced, the search for biological material and published spectral signatures for these types of vegetation was a useful, if not essential, undertaking. Examination of this information made it possible to understand the types of images apparent on the photography. As an example, it was learned that lichens do not have the same reflectance characteristics as higher order plants. The lichens have a much lower chlorophyll content, resulting in less absorption of the green and especially red wavelengths, and less reflection of the near-infrared wavelengths than is typical for most plant surfaces.

4.5.2 Remote Sensing Aspects of the Results

The colour infrared aerial photography provided a valuable source of information for the recognition and mapping of landscape types at Pen Island. Several interesting factors regarding the use of this sensing package became apparent during the interpretation process.

Colour hue and chroma (tone) tended to be very important criteria for distinguishing among classes of landscape types. Some categories could be identified on the basis of these factors alone;

for example, the peat meadow (211), the spruce forest (214) and the recent burn (104). Others required the use of the elements of texture, shape, pattern and/or site, in addition to hue and chroma, for effective recognition. The peat plateaus (213), the sedge meadow (212) and the spruce-lichen woodland (103) fit into this latter group of landscapes. Three image characteristics commonly used in airphoto interpretation, shadow, size (relative and absolute) and stereoscopy (variations in height), were not important in this investigation, largely due to the nature of the Pen Island environment and the small scale of the photography.

The superwide angle lens employed in the photographic mission at Pen Island yielded images at a small scale. This resulted in wide areal coverage on each frame, a definite advantage when a large area must be covered. Besides reducing the cost of film, it also decreased the number of photographs that had to be aligned and studied. In this investigation, only 10 frames were required, but if photography at a more popular scale of 1:30,000 had been used, then as many as 60 images would be needed. Further, as they would be obtained with a longer lens at a lower altitude (4600 m as opposed to 6100 m), the relief distortion would be a greater problem than it was with the actual Pen Island photography.

While the superwide angle lens was a valuable component of the Pen Island sensing package, it created a number of difficulties in the resulting photography as well as assets. The relief displacement and image density distortion have already been described in this chapter, as have the extra steps that had to be taken to minimize their effects.

Another problem became apparent during the interpretation of the peat plateaus (213). These are areas of conifers with a moss or moss-lichen undercover that is visible to the sky through a slightly open crown. Near the photo centre,where the camera is almost directly overhead, the undercover forms a considerable proportion of the image. Toward the edges of the photograph, however, the large oblique angle causes much less of the floor to be visible from the camera station, producing a very different image of the peat plateau.

The colour infrared type of film was an excellent data source for the biophysical mapping of the Pen Island area. As its near-infrared sensitivity is especially suited to detecting surface water and variations in vegetation, it was ideal for the landscape at Pen Island, with its extensive wetlands and wide range of plant types. (These include lichens, mosses, grasses and sedges, hardwoods and conifers.) As a result of the different degrees of surface wetness and the different patterns of radiation reflectance, a very large number of landscapes could be distinguished.

The information content of the colour infrared film for the Pen Island area was, in fact, so great that much more detail could be obtained than had been mapped at the land-type level. Some of the additional data available included variations in the amount of standing water in the sedge meadows, the degree of maturity of the palsa bogs and the extent of crown openness in the woodland landscapes.

4.5.3 Environmental Aspects of the Results

The airphoto interpretation has produced a biophysical classification of the landscape at Pen Island. The resulting map may be examined in terms of the environmental information that it contains.

The aerial photography of the Pen Island area shows only the vegetation cover, but the distribution of the different plant types is related to several other aspects of the environment. By combining the photo data with information gathered at specific points during the field investigation, the nature of these other parameters can generally be inferred with a high level of precision. An example from the Pen Island study is provided by the areas which have a predominantly lichen ground cover. The lichen surfaces that are visible on the photography are known from the field work to be associated with relatively well-drained sites, including the relic beach ridges and the peat plateaus. If a photo image of a lichen surface is long and narrow with straight sides, then it is a ridge site. If, however, the image is shorter and wider, and has a bead-like plan view, then it is a peat plateau. Knowing the type of site, several other environmental conditions, notably the parent material, peat depth and drainage, can be inferred from the ground studies. Following this type of procedure, a biophysical map can be constructed on the basis of airphoto interpretation and limited field investigation.

The completed biophysical analysis of the Pen Island area is considered by this writer to be reasonably precise. Once the key system had been adopted, the different categories of landscapes were generally distinguished without difficulty. One problem, however, continued to exist throughout the interpretation process. In the area further inland beyond that examined in the field, there was confusion among the spruce-lichen woodland (103), the old burn (105) and the peat plateau (213). While there were some sites that clearly belonged to one of the three classes, there were many more that had the basic linear shape of the spruce-lichen woodland, the typical appearance of the peat plateau on the seaward side, and the general look of the old burn on the landward side (Figure 4.5, lower left). The widespread occurrence of this type of landscape implies that it is not an anomoly but is in fact a distinctive biophysical unit. Yet, due to the lack of field investigation, it cannot be positively identified. It is suggested on the basis of its spectral characteristics that it may be a revegetated old burn.

The biophysical map of Pen Island, produced by the airphoto analysis and included in the back pocket, is obviously very complex. To simplify its appearance, the map was examined in detail and the spatial relationships among the different classes were learned. This knowledge was then used to create a generalized view of the Pen Island landscape. The spatial model is presented in Figure 4.7 as a planimetric map and in Figure 4.8 as a longitudinal profile drawn perpendicular to the coast. Examination of these illustrations indicates that the drainage conditions are the most important element controlling the local distribution of the different landscapes.

When the entire area of study is considered at one time, the spatial relationships among the landscape units at Pen Island imply a temporal ordering as well. This ordering is related to the distance from the modern coastline, which is an expression of the time since emergence from the sea in this area of active isostatic uplift. The longer an area has been exposed, the longer environmental processes

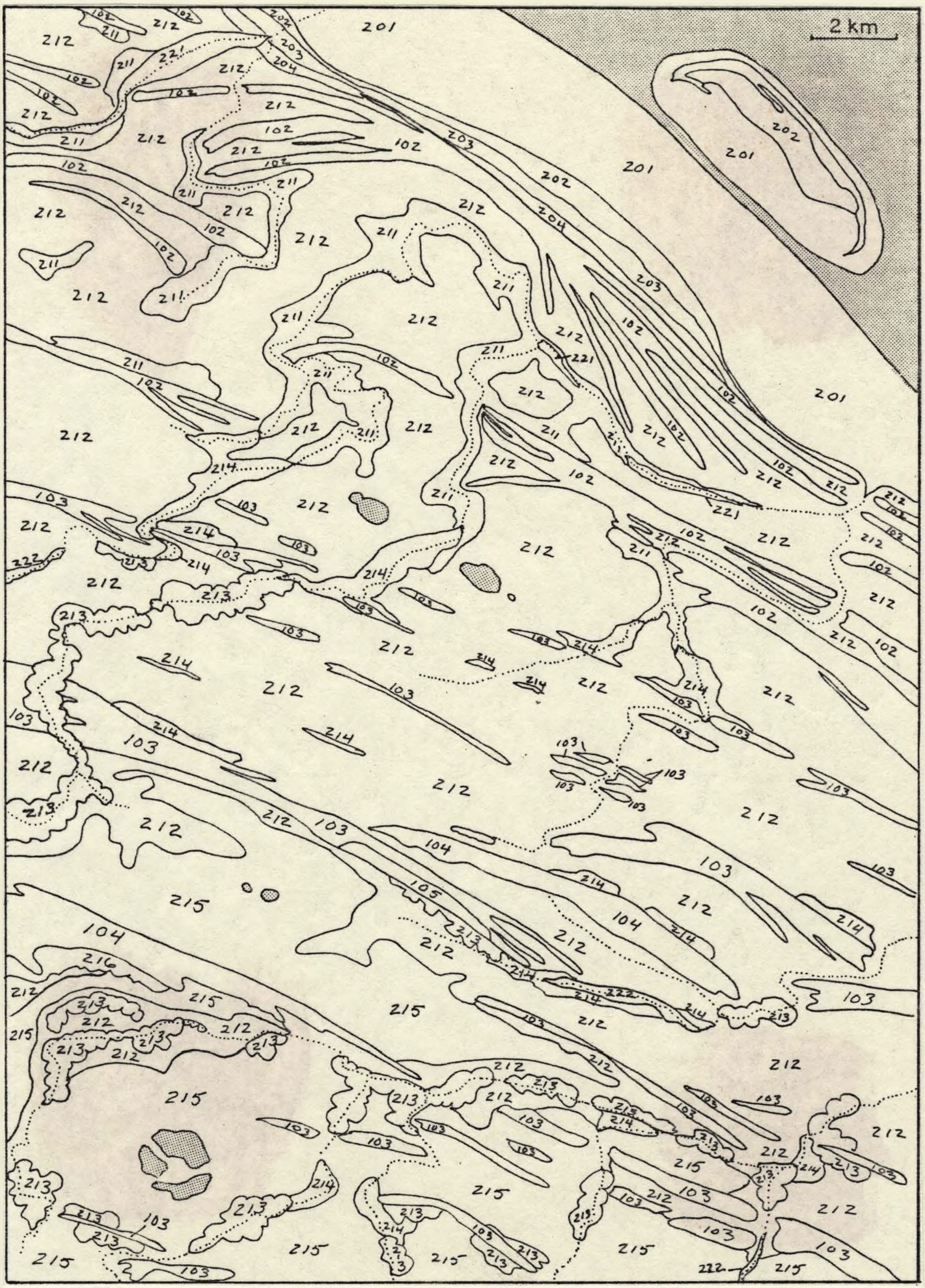


Figure 4.7 Spatial model of landscape at Pen Island. For identification of classes, see Table 4.II.

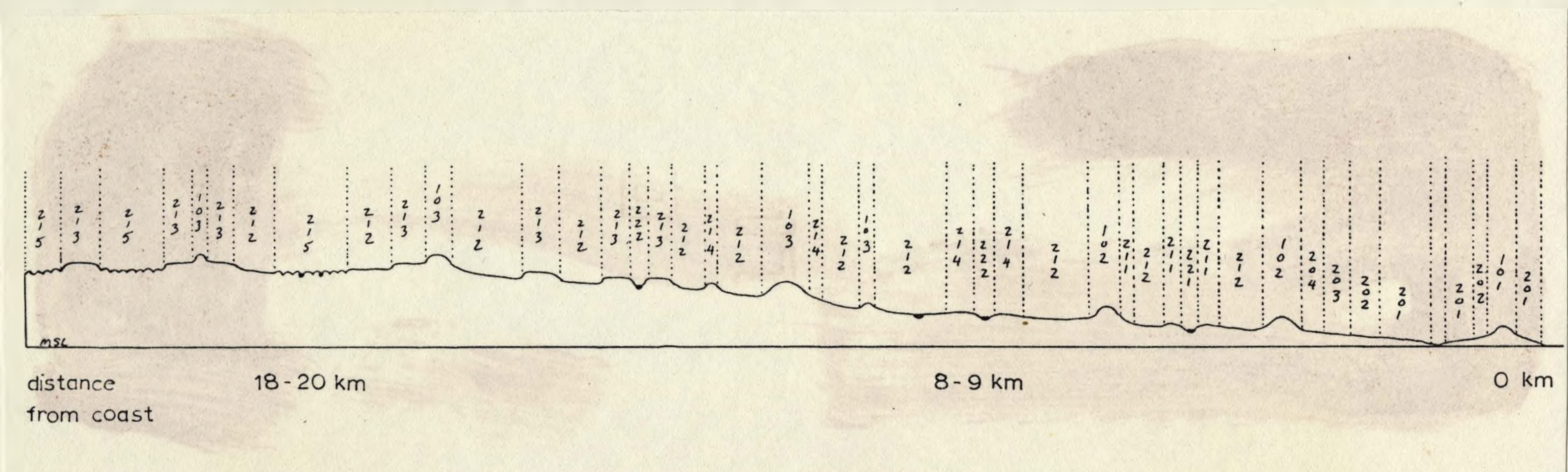


Figure 4.8 Schematic longitudinal profile across landscape at Pen Island. For identification of classes, see Table 4.II.

have had to modify the initial landscape. As a result, a temporal model, in addition to the spatial one, can be constructed for the Pen Island area. This information is presented in Table 4.V on the following page.

4.6 Summary and Conclusions

This chapter has concerned the airphoto analysis of the Pen Island area, which was undertaken to provide spatial information about the types of landscapes in the area as well as a body of ground truth for the analysis of the satellite data. It has reviewed the nature of the remote sensing material employed in the study, and has outlined the procedure followed in the interpretation and the results obtained. The values of the methodology have been discussed, as have the remote sensing and environmental aspects of the results.

The airphoto analysis of the Pen Island area has relied upon small-scale colour infrared aerial photography as its main source of information. This type of photography is sensitive to the longer visible and the near-infrared wavelengths, the latter of which are especially suited to detecting variations in moisture conditions and vegetation types. Its colour assignments are different than those of normal colour film, leading to images that display false colours. At Pen Island, the photography was obtained with a superwide angle lens. This has created a much desired small scale, which permits wide areal coverage on each frame, but it has also produced a less wanted distortion of relief and image density, which makes the interpretation somewhat more laborious than it would otherwise be.

TABLE 4.V

TEMPORAL RELATIONSHIP OF LANDSCAPE

UNITS AT PEN ISLAND

Site Characteristics	Distance from Coast	Time Period	Upland	Wetland			
exposure to saltwater	0 km	t_0	101	201	202	203	204
exposure to freshwater, treeless zone	0-8 km	t_1	102		211	212	221
exposure to freshwater, wooded zone	8-18 km	t_2	103 with 104, 105	213 with 216	214	212	222 some 221
exposure to freshwater, wooded zone	+18 km	t_3	103 with 104, 105	213 with 216	214	215 some 212	222 some 221
Drainage			good	good	fair	poor	good

For identification of classes, see Table 4.II.

To carry out the airphoto interpretation of landscapes at Pen Island, the photography was initially examined and compared with the ground information, in order to develop a suitable classification system. The final scheme was applied to the entire area of study, with the image characteristics apparent on the photographs being used to identify the different classes. Broad physiographic groups were mapped first of all, and then the more specific land types were delineated on a separate base. Recognition of the land types was assisted by the use of keys, which described and illustrated any distinctive photo features of each class, and also by the use of published spectral signatures, which revealed the probable image of certain types of vegetated surfaces. Also of great importance was the ground information gathered during the field season. It was largely these multidisciplinary data that made it possible to identify biophysical and not just botanical units of the land surface.

The completed map of landscape types at Pen Island is complex. Clearly, the small-scale colour infrared photography from which it is produced has a very high information content for biophysical mapping in this type of environment. Some of the land types can even be further subdivided on the basis of their photographic appearance into meaningful classes. The method originally conceived for the airphoto interpretation had to be adjusted to allow for the great detail inherent in the aerial images. Two major modifications were introduced in this light, one involving the use of keys,and the other involving the separate mapping of basic physiographic units and the specific land types. Both categories were delineated at the same scale, the more general one being intended as an organizational guide for the other. At the conclusion of the mapping procedure, it became apparent that the land types could have been portrayed at a two-times magnification for greater clarity. A third modification was introduced to minimize the effect of the relatively strong image density distortion. As the keys were developed for the centre of the image and were not applicable to the darker margins, these parts of each photograph were avoided in the interpretation process.

The identification of land types at Pen Island was frequently achieved by the spectral criteria of hue and chroma (tone) alone, although some categories required additional spatial information as could be provided by texture, pattern, shape and site. The importance of hue and chroma has significant implications for the analysis of satellite data, where the small scale increases the relative importance of the spectral elements and decreases the relative importance of the spatial elements. When digital techniques are employed classification is based solely upon the criteria of hue and chroma.

From an environmental point of view, the completed interpretation of the aerial photography is a very precise portrayal of the Pen Island landscape. There is one biophysical unit of small areal extent whose exact nature cannot be determined, but consideration of its photo characteristics and general knowledge of the environment in the area allow a feasible explanation to be presented. Overall, the final map of biophysical units provides a very fine base for the ensuing study of the satellite data.

Spatial and temporal models of landscape development have been generated for the Pen Island environment, in order to simplify the complicated results of the airphoto analysis. These reveal that the local pattern of landscapes is closely related to the conditions of drainage, but the regional pattern of landscapes is related to the time since emergence from the sea. The spatial model in particular should be useful in the satellite analysis, where the biophysical mapping can readily be extended beyond the Pen Island site to areas of generally similar nature.

Finally, it must be stressed that the field investigations and the literature study were essential inputs to the airphoto interpretation. Without this type of data, only a very unsatisfactory analysis of landscapes at Pen Island would have been achieved.

CHAPTER V

ANALYSIS OF SATELLITE DATA

5.1 Introduction

Remote sensing data obtained from earth-orbital satellites are a new source of information available to virtually all interested investigators in North America. With their repetitive coverage, relatively high spatial resolution and wide areal view, they are especially appropriate for the inventory and monitoring of environmental phenomena over large areas.

The LANDSAT satellites provide remote-sensing data of the visible and near-infrared wavelengths in pictorial or digital format. The sensing systems detect the same bands of radiation as colour infrared aerial photography, which is, therefore, a logical and effective source of "ground" information. As the satellite data are recorded in numerical form, they are ideally suited to digital or automated techniques of analysis.

At Pen Island, the interpretation of the colour infrared aerial photography has produced a body of knowledge that can be used to evaluate the satellite method of remote sensing as a source of information for biophysical mapping. A number of studies have indicated that the satellite data are adequate for general landscape mapping, but a cursory view of the imagery for Pen Island reveals that specific land types can be easily recognized. As a result, an attempt is made to map these more detailed units from the LANDSAT images. The various land types are generally spectrally distinct on the pictorial displays, which implies that digital analysis is also a feasible method of mapping the biophysical character of the area. In consequence, a number of different digital procedures are applied to the quantitative LANDSAT data, in order to identify the specific categories of landscapes at Pen Island.

This chapter reports the procedures and results of the various techniques of analysis applied to the LANDSAT satellite data for Pen Island. Also presented are discussions and comparisons of the classifications achieved by the different methods. To familiarize the reader with the nature of the satellite data,the relevant aspects of this recently acquired type of remote sensing are reviewed before the Pen Island studies are described.

5.2 Nature of LANDSAT Data

LANDSAT is the name now applied to the Earth Resources Technology Satellites (ERTS) of the United States National Aeronautics and Space Administration (NASA). They are spacecraft designed to collect information about the earth's surface by means of remote sensing for use in a variety of disciplines. Currently, there are two satellites in orbit around the globe. LANDSAT 1 (formerly ERTS-1) was launched in July of 1972 and LANDSAT 2 was launched in January of 1975. While both spacecraft are operational at the present time, LANDSAT 1 has outlived its expected lifespan and is beginning to show signs of deterioration.

LANDSAT is an earth-orbital satellite that circles the globe 14 times a day at an altitude of 905 km above sea level. It follows a near-polar orbit, travelling from NNE to SSW on the southbound half of its journey. The orbit is also synchronized with the sun, in order that data for each site are recorded a few hours before local solar noon. With the conclusion of each orbit, the satellite has moved westward. After 18 days of motion, it has travelled completely around the globe and begins to repeat the cycle. Hence, the LANDSAT spacecraft provides sequential data of the earth's surface on an 18-day interval. As long as both satellites continue to operate, however, coverage is obtained for a given site once every nine days due to the relative positioning of the two spacecraft and their travel along the same orbital paths.

LANDSAT 1 and LANDSAT 2 are equipped with identical instrumentation for remote sensing of the earth's surface. Each carries a Return Beam Vidicon (RBV) camera system and a Multispectral Scanner (MSS). The failure of the RBV on board LANDSAT 1 and the demonstrated value of the MSS data have led to heavy reliance upon the scanner material for environmental analysis.

The LANDSAT multispectral scanner records radiation reflected from the surface of the earth. It is sensitive to the wavelengths from the green to the near-infrared region of the electromagnetic spectrum. When this band of reflected radiation reaches the scanner, it is apportioned into four smaller spectral bands, as are described in Table 5.I.

TABLE 5.I

PRINCIPLES OF OPERATION

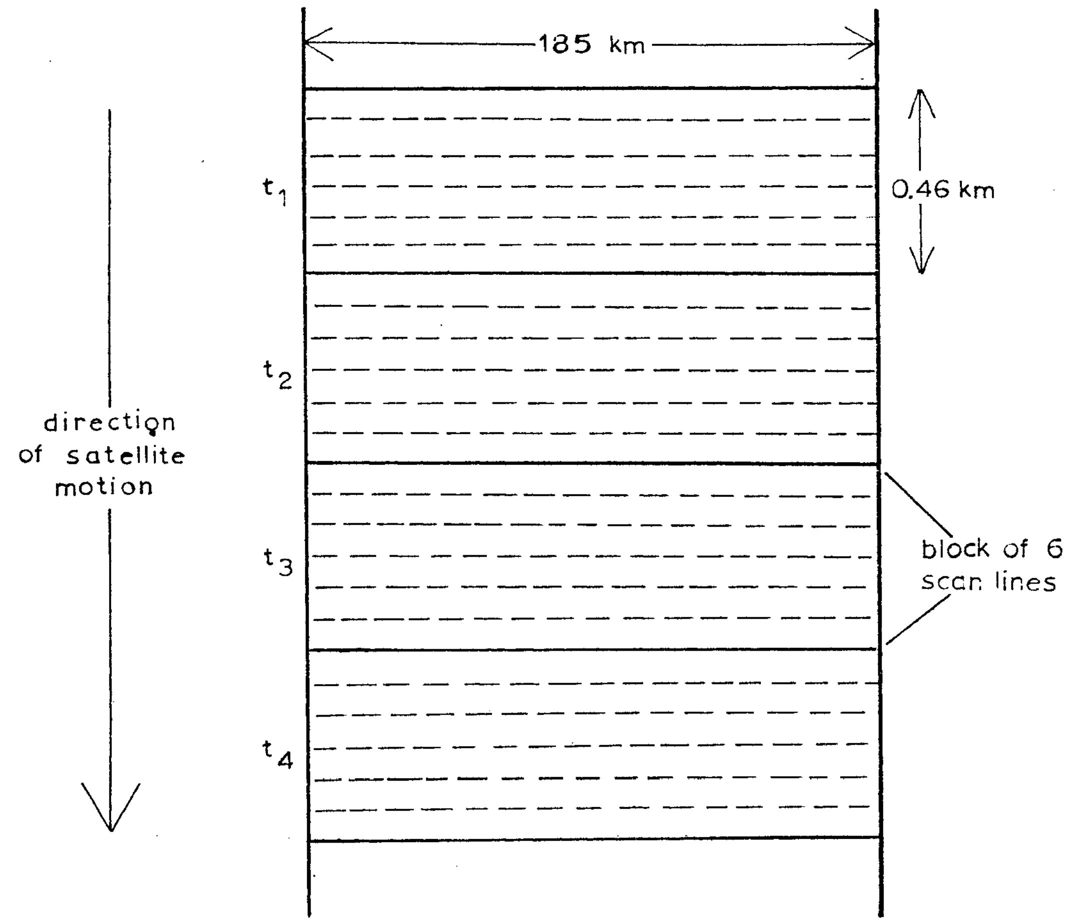
FOR THE LANDSAT MULTISPECTRAL SCANNER

Band Number	Spectral Sensitivity	Spectral Region
4	0.5-0.6 μm	Green
5	0.6-0.7 μm	Red
6	0.7-08 μm	Near Infrared
7	0.8-1.1 μm	Near Infrared

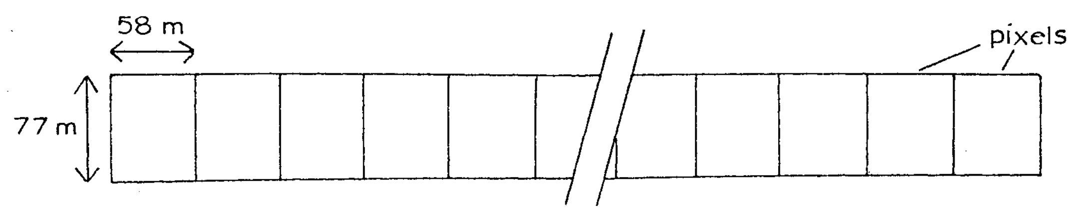
As the LANDSAT spacecraft moves along its orbit, the scanning system collects data from directly below the satellite over a path 185 km wide. The MSS operates in lines across this path from one side to the other, scanning six lines at a time with each line being 77 m wide. Along each line, data are recorded at increments of 58 m (Figure 5.1). In effect, the MSS divides the earth's surface into compartments 77 m long and 58 m wide. These are referred to as picture elements or pixels. The scanner then collects radiation data from each pixel by integrating all the variations in surface reflectance within that compartment. By the time the scanner has covered a block of six lines from one side of its path to the other, the satellite has moved forward in its orbit enough to permit the next section of the earth's surface to be examined. The combined horizontal and forward motion of the sensing system produces a distortion of spatial relationships, but the pattern of distortion is predictable and can be eliminated during processing at a later time.

Unlike the camera system, the scanner converts the incident radiation into an electrical signal rather than recording it directly on photographic film. The LANDSAT MSS expresses the intensity of incoming radiation as a number from 0 (representing a minimum intensity) to 63 (representing a maximum intensity). Each pixel is assigned four numbers, one for each spectral band, and these are combined mathematically to create an intensity vector for the pixel.

As the data are being gathered by the MSS on board LANDSAT, they are simultaneously transmitted to satellite receiving stations on the earth's surface. In Canada,data are received at Prince Albert,



Six lines are scanned simultaneously.



Each scan line is divided into 3200 pixels.

Figure 5.1 Geometric configuration of LANDSAT satellite data

Saskatchewan, except in extreme eastern Canada, where they are received at an American station. At these locations, the intensity vectors are recorded on magnetic tape, which may then be processed to give pictorial displays for visual analysis or computer compatible tapes for digital analysis.

Images of the LANDSAT data are produced in Canada through the Canada Centre for Remote Sensing (CCRS) and the National Air Photo Library (NAPL). The radiation intensities are converted to grey-level values, and these are used to generate positive images (a higher radiation intensity is represented by a lighter tone). Each orbital path of 185 km width is partitioned into 185 km sections along its length, resulting in scenes that are 185 km by 185 km or 3200 pixels by 2400 lines. These standard images measure 18.5 cm square and have a scale of 1:1,000,000. Enlargements are also produced up to a scale of 1:250,000 (a four-times enlargement). Available as paper prints or film transparencies, LANDSAT images may be obtained for each of the four spectral bands or as three-band colour composites, one of which simulates colour infrared aerial photography (Table 5.II). The nature of the photographic process causes some inevitable loss of detail in all forms of LANDSAT imagery. Neither the 64 different grey levels nor every pixel can be portrayed. Nevertheless, the information content of the images may be very high, as has been proven in numerous investigations to date.

The data recorded on the computer compatible tapes are identical to the original data on magnetic tape, the only difference being that the intensity vectors have been translated into a form suitable for

TABLE 5.II

COLOUR COMPOSITES

PRODUCED FROM LANDSAT SCANNER DATA

Colour Composite Number	LANDSAT Band	Spectral Sensitivity	Colour Assignment
1	4	0.5-0.6 μm	Blue
	5	0.6-0.7 μm	Green
	6 or 7	0.7-0.8 or 0.8-1.1 μm	Red
2	5	0.6-0.7 μm	Red
	6	0.7-0.8 μm	Green
	7	0.8-1.1 μm	Blue

computer handling. Unlike the LANDSAT images, therefore, the tapes suffer no loss of information in their processing.

5.3 Visual Analysis

5.3.1 Procedure

LANDSAT data from July, 1972 to June, 1975 were examined for the Pen Island area using the ERTS (LANDSAT) Imagery Catalogue and the Browse Facility of CCRS. From these frame E 1364-16341 recorded on July 22, 1973, was selected for study. Data obtained on this date were free of snow and cloud and were of excellent quality over the land surface. Further, they were collected only one day before the colour infrared aerial photography was flown. The similar date of the photography and the precision of its investigation would be valuable in the analysis of the satellite data. The area within the LANDSAT image corresponding with that used in the airphoto interpretation is portrayed in Figure 5.2 at a scale of 1:500,000.

To carry out the visual analysis, film transparencies at a scale of 1:1,000,000 were purchased for the four bands as well as the two colour composites of the July data. Transparent images generally contain more detail than paper copies at this size, since the grain of the paper reduces the spatial resolution. Two-times enlargements of the six transparencies were obtained as paper prints, both for illustrative purposes and for aid in the interpretation. Also purchased was a four-times enlargement of Band 6, for it was hoped that its scale of 1:250,000 would provide a suitable base for mapping.

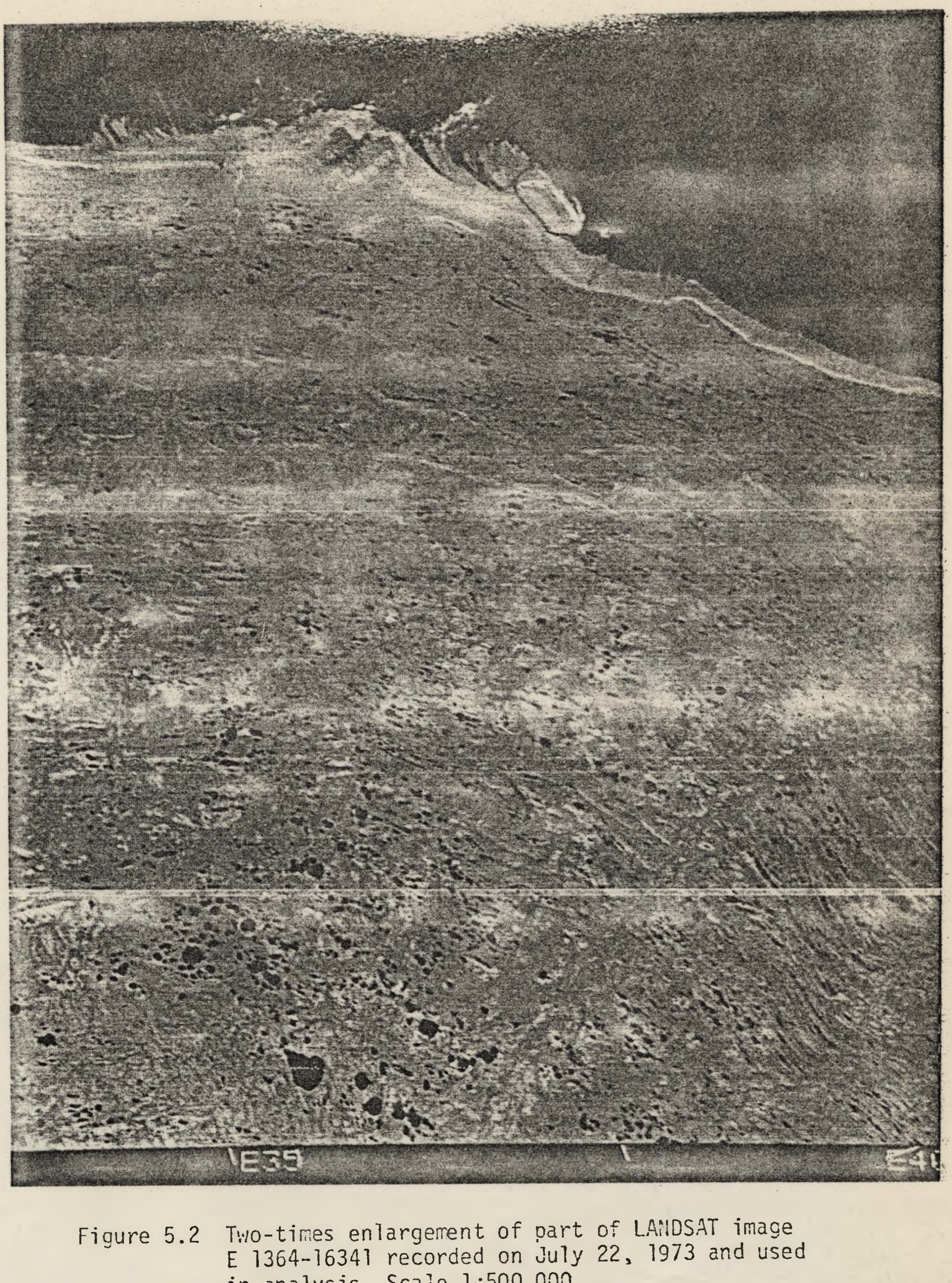


Figure 5.2 Two-times enlargement of part of LANDSAT image E 1364-16341 recorded on July 22, 1973 and used in analysis. Scale 1:500,000 .

It was realized at the outset that visual analysis of the LANDSAT imagery for the Pen Island site could very easily be biased by the preceding detailed study of the aerial photography. As an example, landscape A may be quite different from landscape B on the photography, yet on the satellite imagery they may be very similar. Knowing that they are in fact different, it would be very tempting to separate them on the LANDSAT data. Clearly, an investigation of the information content of the LANDSAT imagery necessitates the elimination or at least the minimization of such bias. To this end, it was decided that numbers alone would be assigned to the different classes as they were mapped, rather than numbers and names as in the airphoto analysis. Further, any photo consultation would be avoided until the interpretation was completed.

The first stage of the LANDSAT analysis involved the identification of different classes on the imagery and the recognition of their image characteristics. After comparing imagery from the four bands and their colour composites, colour composite 1, the simulated colour infrared image, was selected for study. The colour transparency was placed on the Richards Light Table and was examined through the Bausch and Lomb Zoom 240R Stereoscope. This optical device allows monocular or stereoscopic vision of photographic images, at the original scale or with magnification up to thirty times. Using the image qualities of conventional airphoto interpretation, the scene characteristics of the apparent classes were learned. This consisted of studying the different combinations of hue, chroma, texture and shape that made various parts of the image distinctive.

In the second stage of the visual analysis, the definitive image characteristics, already learned for the various classes, were used to produce a map of these classes over the area studied in the airphoto interpretation. The colour transparency employed in the training process was mounted in a Bausch and Lomb Zoom Transferscope and the four-times enlargement of Band 6 was placed underneath to serve as a map base. By means of this instrument, information can be transferred from the transparency to the less detailed photo base.

This initial means of visual analysis of the LANDSAT imagery proved to be highly unsatisfactory. As with the airphoto interpretation, the difficulty in mapping at Pen Island seemed to be related to the complexity of the landscape and the very detailed sensor record. Two major problems were encountered. First, the four-times enlargement of the original LANDSAT scene, which gave a mapping base at a scale of 1:250,000, was inadequate for recording all the information visible on the transparency with only slight magnification by the Zoom Stereoscope. Second, the intricate patterns and narrow linear features of the Pen Island landscape were readily apparent on the LANDSAT image, but these became very confusing in the Zoom Transferscope. This instrument has a weaker lighting system than the Richards Light Table, resulting in considerable reduction of detail. Even had the map scale been sufficiently large, this imposed loss of information would have been too great to effectively map all of the classes detected on the transparency.

It was not until the digital analysis of the LANDSAT data was begun that a solution to the problem in the visual analysis was found.

The first step in the computer study involves the display on a television screen of the total image from three of the four bands recorded on tape. Subsequently, the desired area of study is chosen and shown on the monitor at a user-specified scale. For the Pen Island study, the selected area was portrayed using Bands 4, 5 and 6 with a two-times magnification. The resultant "colour infrared" image was clearly suitable for visual analysis. Photographs of the scene were taken with slide and print film, and the print is reproduced in Figure 5.3. The horizontal scale of this illustration is 1:140,000. In the vertical direction, the scale is not the same, since the rectangular rather than square shape of the pixels creates a slight vertical squeezing of the image on the TV screen.

Visual analysis of Figure 5.3 was carried out using a procedure much like that already described. A map base was produced by projecting the slide onto a firm surface covered with tracing paper and adjusting the projecting distance to give a horizontal scale of approximately 1:30,000. The slide and print were then examined, in order to recognize the different combinations of hue, chroma, texture and shape that signified different classes. Finally, this training information was applied to the projection and areas of similar image characteristics were delineated. Working within drawing range of the projected image caused some loss of resolution, but this problem was overcome by studying the paper print at the same time.

Upon completion, the LANDSAT imagery interpretation was compared with the airphoto interpretation as well as the aerial photography, and similarities and differences were examined. The entire analysis

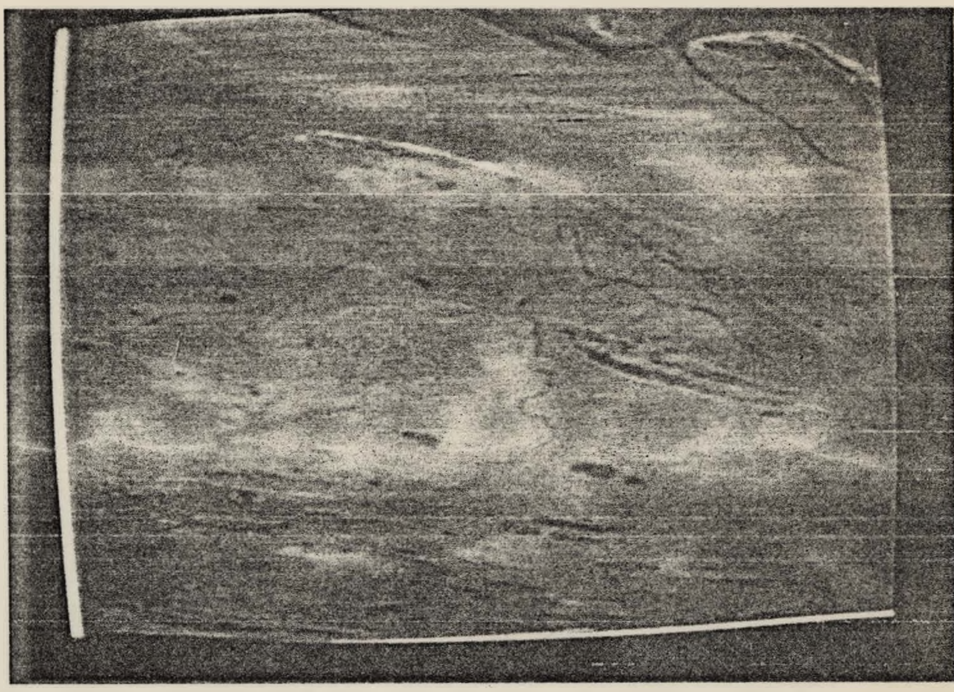


Figure 5.3 Scene of Pen Island area displayed on MAD system and used in visual analysis

was carried out prior to the supervised digital classification, thereby providing a useful base from which training areas could be chosen.

5.3.2 Results

The completed visual analysis of the LANDSAT data for the Pen Island area is presented in Figure 5.4 at a scale of 1:80,000. The scale has been reduced from the original for illustrative purposes.

During the training process, it became apparent that the many images over the area of study could be organized into four basic groups. Accordingly, each class was symbolized by a number from one to four. Correlation with the aerial photography allowed the classes to be easily explained. The four groups are as follows:

Type 1 Medium-dark blue to blue-black areas of smooth texture are included in the first class. These represent open water, and their darkness is due to the absorption of near-infrared radiation by the water surface.

Type 2 The second group is defined by white to pale blue areas of smooth to medium texture, some of which have a narrow linear form. It characterizes areas of bare ground that have relatively high reflectance in all bands.

Type 3 Areas of grey, grey-brown or reddish grey colouring that range in tone from light to medium dark and have a medium to medium-coarse texture typify the third type of image. Some areas have a narrow linear shape, while others are more amorphous and appear to form a "background". These are vegetated areas that have a comparatively

Figure 5.4 Visual analysis of LANDSAT image displayed in Figure 5.3 For legend see text.

low reflectance in the near infrared.

Type 4 The fourth class is composed of red areas with a very light to medium-dark tone and a medium texture. Some of these areas are broadly linear. The red colouring is the product of reflection in the near-infrared band of radiation that is high relative to that in the other bands. As with Type 3, this class consists of vegetated areas.

Each of the four basic groups of images identified on the LANDSAT data were subsequently divided into a number of constituent classes. These could generally be distinguished without difficulty, and were readily identified on the aerial photographs. Designated with a letter symbol following the type number, these subdivisions are described subsequently. Their relationships to the classes of the airphoto interpretation are summarized in Table 6.I.

Class 1A This class has a medium blue image of smooth texture. It is identified as turbid water, generally seawater along the shallow coast, but also a few freshwater lakes on the mainland. While water normally appears very dark on colour infrared images, a load of suspended sediment lightens the image due to its high reflectance values.

Class 1B A very deep blue, smoothly textured image designates clear water on the LANDSAT imagery. Nearly all of the freshwater lakes fall into this category, as do areas of open water along the river courses. The lack of turbidity in these waters means that there is nothing to counteract the very high absorption by water of radiation in the four LANDSAT bands.

Class 2A This pale blue, smooth- to medium-textured class corresponds with the area of extensive tidal flats identified on the aerial photography. Composed of sand and mud, the flats are wet and bare of vegetation. Their broadness on the LANDSAT imagery suggests that these data were recorded at or near low tide. Variations in their appearance are considerable, and are thought to be related to differences in the grain size of the material and the resultant moisture characteristics, as well as differences in the length of subaerial exposure.

Class 2B These smooth white areas of narrow linear form are bare sand and gravel. The low moisture-holding capacity of the material causes extreme surface dryness at Pen Island, and this combined with the mineral composition of the deposits leads to a very light image. Class 2B includes new beach systems and also areas of wind erosion on the relic beach ridges.

Class 3A Zones of grey-brown colouring, sometimes with a tinge of red, that have variable tone and texture are identified as Class 3A. The non-descript colour and lack of any pattern make this class appear as a background upon which many others are superimposed. It represents the sedge meadow wetland that covers much of the young treeless landscape at Pen Island. Variations within Class 3A are created by differences in the depth of standing water and, in turn, the type and amount of plant growth. The proportion of water to vegetation in each pixel causes the intensity vectors to vary considerably from pixel to pixel.

Class 3B This class contains medium-light grey areas with a fairly smooth texture and a narrow linear shape. It denotes the lichen heath, a region of predominantly lichen vegetation which occurs on the relic beach ridges. The preceding chapter has already described how lichen differs from higher order vegetation and how this results in a peculiar pattern of spectral reflectance. Most of the ridge complexes apparent on the aerial photography can also be detected on the LANDSAT imagery; however, rarely are they totally visible. Very narrow ridges and the extremities of more prominent ones cannot be recognized on the satellite data, as can be seen when the upper left of Figure 5.3 is compared with that of Figure 4.3.

Class 3C The narrow linear pattern and grey colour of Class 3B also characterize Class 3C, yet this category may be separated from the former by its more mottled and lighter toned image and reddish tinge. It defines the spruce-lichen woodland of the older relic ridges. Unlike the vegetation mat in 3B, this one is comprised of almost pure *Cladonia alpestris* lichen, a species which has a distinctive, pale grey-green appearance in the visible band of radiation. There is also a coniferous woodland present in 3C, where the crowns tend to be widely spaced but are large enough to cause some reddening and mottling of the lichen image. As with 3B, very narrow areas of the spruce-lichen woodland are not detected on the LANDSAT images, but all larger sections can be distinguished.

Class 4A This class is set apart from others by its light pink image of medium-smooth texture. Comparison with the aerial photography indicates that it is the peat meadow. Its pale colouring reflects the presence of lichens in the mixed plant cover and the absence of standing water over this wetland landscape. The areal distribution of Class 4A is very similar to that revealed in the airphoto analysis. Even small isolated areas are readily identified on the LANDSAT imagery.

Class 4B Areas with a light to medium orange colour and medium-coarse texture map out the location of the young saltmarsh. As this is the site of initial plant colonization of the tidal flats (Class 2B), the vegetation cover is incomplete, resulting in a rather coarse appearance on the LANDSAT imagery. Class 4B corresponds closely with the young saltmarsh adjacent to the mainland, but it also includes the area in the lee of East Pen Island. This area of young saltmarsh could not positively be identified as such on the aerial photography, due to the image density distortion problem. Also placed in Class 4B are parts of the river courses where grasses and willows grow, but these are too small to be delineated on the map.

Class 4C With its medium red, medium textured image, Class 4C represents the mature saltmarsh. Vegetation species have changed from what they were in Class 4B and the plant cover has become complete. This is an area of high biological productivity, as is indicated by the strong red colouring that is characteristic of vigorous plant growth. As with 4B, the location of Class 4C is similar to the mature marsh on the aircraft data, but it also includes some of the riverine vegetation.

Class 4D This small class has a medium red-grey appearance with a medium-smooth texture. It identifies the transitional marsh that is a combination of saltwater and freshwater plants. Environmentally, it falls somewhere between the mature saltmarsh (Class 4C) and the sedge meadow (Class 3A). The image of this class is also transitional between 4C and 3A. No areas are incorrectly classified as being part of this unit.

Class 4E Deep red to red-brown areas of medium texture are placed in Class 4E. Often they have a distinct red line running through them. These areas are equivalent to the spruce forest and the peat plateaus of the airphoto analysis. The red lines mark the location of streams with grasses and large willow shrubs along their banks. The surrounding red to red-brown areas denote the coniferous trees. The darkest areas have close-crowned forests, while the less dark, more mottled areas have open-crowned woods. The latter are usually indicative of the peat plateaus, where the moss-lichen ground cover under the spruce is open to the sky, but they also occur on the extremities of the closed forests. While Class 4E combines two classes on the aerial photography, its distribution is close to that of the two classes together. Omissions are generally confined to very narrow areas, or to parts of the peat plateaus where there are very few spruce.

Class 4F This class is characterized by a bright orange-pink colour and medium texture. It has no counterpart in the airphoto analysis. Examination of the original photographs reveals that 4F largely depicts the marginal parts of the older sedge meadow in the partially wooded zone, but it also includes many very narrow ridges of spruce forest. These are not actually visible on the LANDSAT data, but their presence is detected by the existence of the marginal sedge on either side. The sedge meadow of this class has more luxuriant growth than that in Class 3A, and also has some different plant types, including a thick growth of deciduous and coniferous shrubs. The result is a considerably redder image than occurs in other areas of sedge meadow.

Class 4G Two unique areas having a coarsely textured, medium-dark image of brown colouring, are designated as Class 4G. Like 4F, this class was not delineated in the airphoto interpretation, but is readily apparent on the photography. It represents another variation of the sedge meadow, but its exact nature is not known. Based upon its colour on the aircraft and satellite images, this class may identify parts of the older sedge meadow dominated by coniferous vegetation, likely tamarack (*Larix laricina*).

Class 4H This class is defined by its heterogeneity of appearance and winding linear pattern. It portrays the river courses in the young treeless landscape near the coast. In reality, it is a mixture of the dark blue of Class 1B, the orange of Class 4B, the medium red of Class 4C and the rather dark grey-brown of Class 3A. The smallness of the areas belonging to each of the component classes made it impossible to map them individually.

5.3.3 Discussion

During the course of the visual examination of the LANDSAT imagery for Pen Island, there emerged several points that are worthy of further comment.

The preliminary study of imagery from the four spectral bands and their two colour composites indicated that Bands 4 and 5 were poor for visual analysis of the Pen Island environment. These two images of the longer visible wavelengths had low contrast over the area of study, and the water bodies which served as reference markers were often indistinct. Greater tonal variation was apparent on imagery of Bands 6 and 7, the near-infrared bands. In these wavelengths, the plants covering the landscape at Pen Island showed increased spectral diversity. Further, the open water and wet areas were easily distinguished. Colour composite 1, a combination of Bands 4, 5 and either 6 or 7, was selected because it had the desirable features of the near-infrared band and also included the visible bands. The information content of the three taken together should exceed that of any one taken alone. This image is also characterized by colour hue, a property which is generally an important asset in visual analysis. The second colour composite was considered to be less useful than the first, since it included Bands 6 and 7, which appeared to be virtually identical over the subaerial landscape at Pen Island.

The interpretation criteria used to identify different classes on the LANDSAT imagery were primarily hue and tone (chroma), but shape and texture were also helpful in some cases. These are the same criteria employed in the airphoto analysis. With the satellite data, however, there is greater reliance on hue and chroma than with the larger-scale aircraft data, and shape and texture are generally less important.

The classes recognized in the LANDSAT analysis correspond very closely with the landscapes identified in the airphoto interpretation, although there was no direct consultation during the mapping procedure. The only landscape not detected was the old burn. The analyzed LANDSAT scene (Figure 5.3) includes a small area of old burn in the extreme lower left, but its smallness of size and peripheral location led to its classification as 3C, the spruce-lichen woodland. Generally, however, the pattern of landscapes over the entire scene, as well as the localized detail, are the same for the LANDSAT and the airphoto analyses.

The similarity of the interpretation criteria and the identified classes in the airphoto and LANDSAT investigations suggests that small scale colour infrared aerial photography is a valuable source of training information for the visual analysis of colour composite 1, the simulated colour infrared image of the LANDSAT data. For a large area of relatively similar nature, for example the young coastal zone of the Hudson Bay Lowlands, aerial photography of only a small portion should be needed to map landscape types over the whole region by means of satellite imagery.

The procedure followed in the visual analysis to obtain satisfactory results requires more discussion. The initial procedure, employing the standard 1:1,000,000 transparency and the Zoom Transfer-scope, is the method ideally suited to visual interpretation of the imagery, yet it was of little value in the Pen Island area. The information content of the satellite data was too high. The area could be mapped at a less detailed level, but then much of the inherent knowledge would be neglected. Also, the grouping of distinct classes during the process of interpretation could be a difficult task.

The revised procedure, using the magnified "colour infrared" image from the MAD television screen, was much easier than the original method of visual analysis and it gave excellent results. It does, however, have two major difficulties. First, there is a problem of practical significance, since the production of the image from the MAD system involves considerable expense. The purchase of a computer compatible tape of the LANDSAT data now costs $200 and expensive computer time is also required. Further, the only MAD system in Canada is the one located in Ottawa, a fact which introduces travel and accommodation costs for many users. In some cases, as in the analysis of a large, relatively homogeneous area that is poorly known, such expenses may be warranted. In many other cases, however, they may be unrealistic. An alternative may be the photographic enlargement of the area of interest from purchased LANDSAT imagery. Second, the vertical squeezing of the LANDSAT image by the MAD television monitor causes a distortion of distance, thereby making planimetric mapping impossible. This problem can be overcome through the use of a special programme in the system, which allows the user to select the correct number of lines and pixels to produce a geometrically correct image.

In comparison with the process of aerial photographic interpretation, mapping from the magnified LANDSAT image was less difficult. There was no distortion of density across the image. This had been a definite problem in the analysis of the aerial photographs. The satellite data also contained less variation in texture than the photography, making hue and chroma predominant and class delineation considerably easier. In addition, to cover the area examined on the one LANDSAT image, six aerial photographs had to be studied. These had to be correctly aligned with each other to produce a base map, a process that was difficult and time-consuming due to the relief displacement inherent in the photography.

5.4 Digital Analysis

Since the LANDSAT data are originally recorded in numerical form, they are ideally suited to computer analysis. Visual interpretation of the data for Pen Island suggests that the digital approach should be successful in the area, as the different landscape types were distinguished primarily by their spectral properties.

There are two systems available at the Canada Centre for Remote Sensing in Ottawa that are capable of using the digital LANDSAT information. These are the General Electric Image 100 and the Bendix Multispectral Analyzer Display systems. Utilizing a PDP computer,each of these machines examines the spectral values in the four LANDSAT bands and performs various statistical manipulations to divide the data into a number of spectrally distinct classes. This may be done by supervised classification, where the user trains the computer to identify classes, or by unsupervised classification, where the natural clustering of the intensity vectors is used to recognize different classes. The results are displayed on a colour TV monitor, with a different colour representing each class. On the Image 100, 8 classes may be portrayed at one time. On the Bendix MAD, however, as many as 32 classes may be displayed simultaneously.

In this investigation, the Bendix MAD System was selected for the digital analysis. This device is considered better for the unsupervised classification than the Image 100 due to the fact that more than 8 classes may be examined at one time (Howarth, 1976). For the supervised method, the Image 100 is easier and faster than the MAD, but its 8-class limit for display is likely too small for the Pen Island data. Further, the system was undergoing major renovations at the time and was not available to users. Hence, the supervised classification was also carried out using the MAD.

5.4.1 Bendix MAD System

The Bendix Multispectral Analyzer Display System does not have its own computer; rather, it works in conjunction with a computer system on a time-sharing basis. The MAD is run by the user himself by means of a series of analysis programmes, which comprise the Modular Interactive Classification Analyzer (MICA). Several HELP files are available, which describe the purposes of the various programmes and how they may be implemented. This differs from the Image 100, where the user works through an operator by telling him what he wants to do. In the summer of 1976, however, with the renovations of the Image 100, the operators were transferred to the MAD to facilitate the increased number of users.

There are four system features of the MAD with which the user must be familiar. These include the input, the display unit, the control unit and the output.

1) Input The computer compatible tapes produced from the original LANDSAT data are the source of information for the MAD system. One tape holds data for one frame (3200 pixels by 2400 lines) of the visual format. The tape is mounted onto a tape drive and its information is then transferred onto a private disk pack. This step is necessary for all analyses, so that the data may be called from storage at any time.

2) Display Unit A colour television monitor displays an image from the data, but only three of the four bands can be shown at one time. The user selects the bands and the colour assigned to each, from red, green or blue. Also portrayed on the screen are the classification results, where colour is assigned to each class automatically but where the user can change the colours to create a more suitable image. The display of classified scenes is important, allowing the user to consider what further steps should be taken in the classification process. There is one difficulty with the TV display unit, however. Since the pixels are rectangular and the television points are square, there is a slight vertical squeezing of the image.

3) Control Unit To manipulate the programmes and thereby interact with the computer, a teletype system is employed. The control permits a two-way communication between the user and the computer for effective LANDSAT analysis. Different teletypes may be utilized,

including those which give a paper print of all procedures, those which display this information temporarily on a screen as an electronic signal but give no permanent record, and those which are located at a remote terminal. The latter are valuable if the display unit is not required for decision making. For instance, the statistical programmes or calculated modifications to an existing classification could be sent from the terminal at McMaster University and the results could then be returned to the University through the mail.

4) Output Once an area has been classified, the information is stored on the private disk pack. Then, three modes of output are available. For one, the image displayed on the TV screen may be photographed using standard film and camera with settings for long exposure time and wide aperture. As an alternative, the information can be written onto a computer compatible tape and produced as an image through the Electronic Beam Image Recorder (EBIR). This system is also used to generate LANDSAT imagery from the original magnetic tapes. Finally, the classified scene and numerous related statistics can be obtained as paper copies by means of the line and Gould printers. The image is portrayed in terms of alphanumeric symbols, with a different one representing each class. The user may then colour each symbol with a differently coloured marking pen.

Using the Bendix system, the classification of the LANDSAT data from a desired area is begun by loading the tape including that area onto the tape drive. Generally, the entire frame needs to be displayed on the monitor before the area of interest can be identified. To generate the pictorial display, the scene must be decimated, since it contains 3200 pixels by 2400 lines and the TV screen contains only 512 by 512 points. One out of every six pixels and one out of every four lines will give an image of the whole scene on the screen.

Within this scene,the user frequently has only a small area that he wishes to study. By producing a Gould map in the form of a binary print of the total scene, the pixel and line coordinates of the area of interest can be approximated. This area can then be displayed on the monitor and loaded onto the private disk pack. If it has more than 512 pixels or lines, decimation is still needed for display. If, however, the area has less than 512, then magnification is necessary. This is achieved by repeating each pixel a number of times. A two-times magnification would call for a four-times repeat, while a three-times magnification would call for a nine-times repeat.

Once the area of interest has been selected and initial procedures are complete,the user must decide whether to carry out analysis by unsupervised or supervised techniques. In the unsupervised approach, there are three steps that must be taken:

(i) Initially, the intensity vectors of all the pixels in the area of study are used to produce a four-dimensional histogram. This is a table listing of the frequency of occurrence of the different intensity vectors.

(ii) The frequency distribution is then studied to identify areas of similar reflectance characteristics, based on the occurrence of natural clusterings or peaks in the distribution. Each of these groups forms a separate class of intensity vectors. The methodology used to identify different classes is described in Goldberg and Shlien

(1976).

(iii) Finally, the classified vectors are assigned colours by the system and are displayed on the television screen.

By studying the classified image on the monitor, the user may decide to change the colours given to each class, to combine certain classes, or to break up others. These modifications are carried out by repeating step (iii) or steps (ii) and (iii). Subdivision of the classes is continued until further division yields new classes which have no relevance to the problem at hand.

Classification of the area of interest by supervised procedures involves training the computer to recognize the spectral characteristics of certain classes and applying this knowledge over the entire scene. This is a four-stage process, and it is longer and more tedious than the unsupervised analysis:

(i) At the outset, a cursor is used to select training sites, based on the ground truth for the area. The sites should be spectrally distinct for each class, and should be quite uniform within each class. Generally, data from 50 different pixels are required to give statistically significant results. As each site is selected, its position is recorded by the system on the basis of its pixel-line location.

(ii) Once all training sites have been chosen,the intensity vectors of each class are analyzed and class statistics are computed.

(iii) Then, the class training statistics are applied to the intensity vectors over the whole area of interest and these vectors are placed into the appropriate classes. When an intensity vector may belong to more than one class, a statistical decision is made by the maximum likelihood rule, placing the vector into the class to which it most likely belongs. If a vector is too far removed from any of the training classes, then it is left unclassified and appears on the monitor as a black image. Details of the classification methodology are presented in Goodenough and Shlien (1974) and Shlien and Goodenough (1974).

(iv) Lastly, the classified scene is displayed on the TV monitor, with colours being chosen for each class by the user from a maximum of 15. As with the unsupervised classification, the initial supervised one may well be unsuitable. When this is the case,the user has several options that he may take. He may combine, delete or expand some of the training classes, or he may generate new classes or modify the colour assignments. These changes are carried out by employing step (i) if new training information is required, or by utilizing an alternative step which allows existing information to be edited. Subsequently, steps (ii) to (iv) are repeated to produce a new classified image. If it is still unsatisfactory,then the modification procedure is followed until no further improvements in the classification can be achieved.

In addition to the unsupervised and supervised classifications, the MAD system also features a means of digital analysis known as "Principal Components Colour Enhancement". This technique does not produce a spectral classification of the LANDSAT data. Rather, it applies a series of transformations to the data with the intention of increasing their colour range and improving feature separability. The procedure realizes that the natural colours of the earth's surface, primarily blue, green, grey and brown, occupy only a small part of total colour space. By mathematical means, the LANDSAT intensity vectors are spread over a greater colour range,in order to produce an image that is easier to interpret. This enhanced scene may portray the earth's surface in shades of red, purple, orange and yellow as well as blue, green, grey and brown.

While detailed descriptions of the workings of the enhancement technique are presented by Taylor (1974) and Taylor and Langham (1975), sufficient information for the MAD user is listed in the HELP files of the system. The procedure broadly resembles the methodology of the unsupervised classification, but it involves only two steps:

(i) First, transformations are carried out for the intensity vectors in an area specified by the user.

(ii) Then, these data are applied to the area and an enhanced image is produced on the TV monitor.

A final note relating to digital analysis of LANDSAT data by the MAD system concerns the extension procedures. Classifications generated by the unsupervised and supervised techniques and transformations produced by the enhancement programmes pertain to specific areas, but the calculations they contain may be applied to other areas within the same LANDSAT frame. Using the original area of study as a training site, a larger portion of the LANDSAT frame may be analyzed simply by specifying different line and pixel coordinates. It is not possible to extend the training information to LANDSAT data from another time or place, that is, to another frame. The spectral properties are invariably different, due to the vast number of environmental conditions that affect the data recorded by the LANDSAT multispectral scanner.

5.4.2 Unsupervised Classification of the Pen Island Site

a) Procedure

The computer compatible tape E 1364-16341, recorded on July 22, 1973, was mounted on the tape drive of the computer and a decimated version of the data was imaged on the television screen of the MAD. From this total scene, an area was selected to include all of the elongated strip studied in the airphoto interpretation. This was not suitable, however, the scale being too small to correlate the classified satellite image with the aerial photographs. It also included wide bands either side of the strip for which there was no existing ground information. A smaller area was chosen with no decimation of the image and with a two-times magnification factor. Although this scene eliminated a part of the area covered by the photo interpretation, it did include the section that had been most intensively studied, and it was at a satisfactory scale. Figure 5.3, employed in the visual analysis, is an illustration of the chosen site.

Once the scene had been selected and the preliminary programmes (the application of radiometric corrections to the intensity vectors and the determination of their four-dimensional frequency distribution) completed, the unsupervised classification programme UNSUPR, version 7.11, was carried out.

The initial run of UNSUPR divided the data into five classes, four representing water and one representing land. Since some of the water classes were insignificant on their own,they were combined to form two new classes. At the same time, the land class was further divided. This gave two water and two land classes (Figure 5.5), one land class marking vegetated areas and the other barren ones. Steps taken following the generation of this simple but valid classification are described in Figure 5.6.

With the exception of the regularly-flooded tidal flats and a few small areas of wind erosion, the landscape on the mainland at Pen Island is a vegetated one. Subdivision of classes in Figure 5.5 was, therefore, limited to the one representing vegetation (dark purple). Based on the visual examination of the LANDSAT image, this class contained many distinct images. Step 3 in the classification process divided the vegetation class into two new groups, as seen in Figure 5.7. Owing to the complexity of the landscape at Pen Island, these two classes were further divided separately, each being broken down three more times (Steps 4 to 6) to produce Figures 5.8 and 5.9 respectively. The two classifications were then united (Steps 7 and 8), and some of the classes were combined as they had little meaning individually (Step 9). The final classified scene is displayed in Figure 5.10.

Consideration of Figure 5.10 indicated that it was highly detailed, and was, in fact, too detailed if the scene were to be used for mapping purposes. Generalization of a classified image produced by the unsupervised technique is possible through the application of various filters. The filtering process compares the intensity vectors of individually classified pixels to those of adjacent pixels

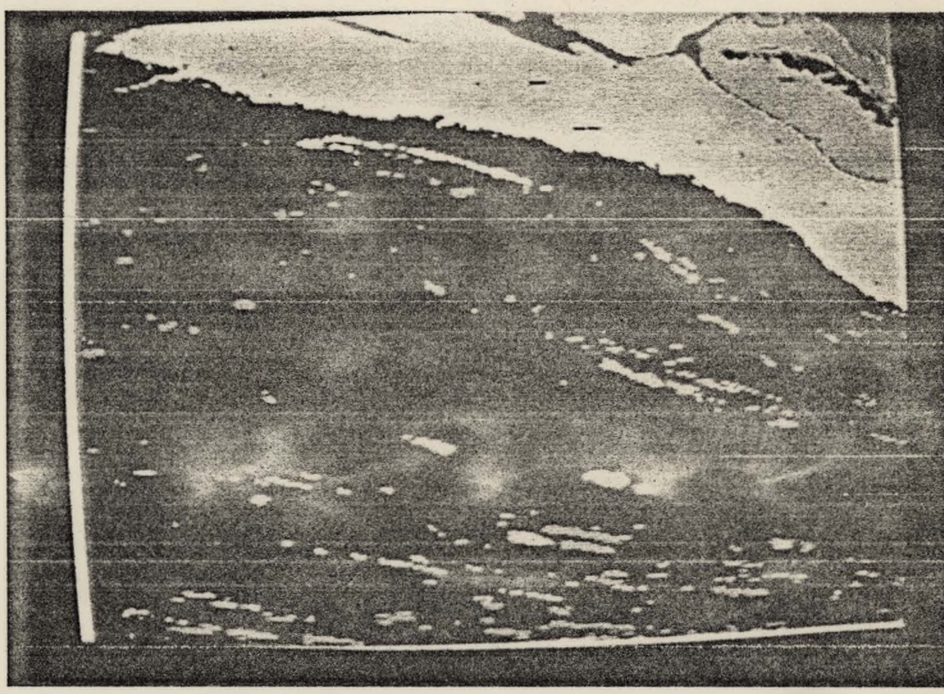


Figure 5.5 Development of unsupervised classification to 4 classes

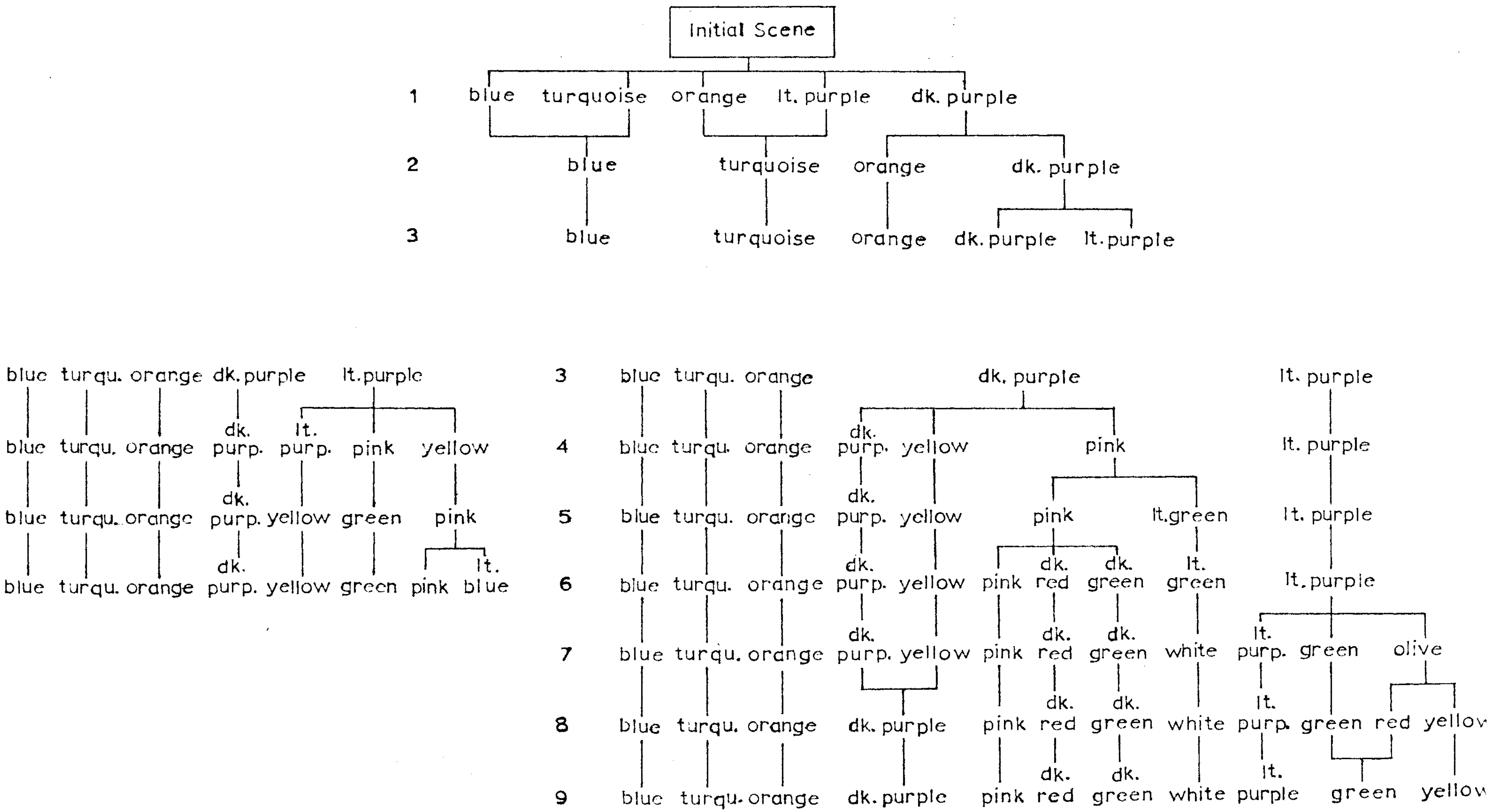


Figure 5.6 Flow chart for unsupervised classification of Pen Island area

Figure 5.7 Step 3 in flow chart for unsupervised classification.

Figure 5.8 Step 6 (left side) in flow chart for unsupervised classification

Figure 5.9 Step 6 (right side) in flow chart for unsupervised classification.

Figure 5.10 Final unsupervised classification produced by MAD system for Pen Island scene displayed in Figure 5.3

that are all classified the same. If the isolated pixels are spectrally fairly similar to the others, then they are reclassified as being the same as the others. This operation assumes that isolated pixels are probably wrongly classified because their intensity vectors are just beyond the limits of the main class. Different degrees of filtering are available. For the Pen Island scene, the weak 3x3 and the strong 3x3 filters were used. The results are presented in Figures 5.11 and 5.12.

To aid in the evaluation of the unsupervised classification, a number of statistics were generated for the final classification. These included the mean reflectance values in the four spectral bands for each of the classes (Table 5.III), the confusion matrix for the total scene (Table 5.IV) and also the two-dimensional plots of the decision ellipses. The latter are visual displays of the statistics using any two of the four bands at one time. They provide an indication of the class separability by means of the degree of overlap among the ellipses. Of the 8 plots generated for the final unsupervised classification, the one of Bands 5 versus 6 had the least overlap and is the one presented in this text (Figure 5.13).

The confusion matrix is another measure of class separability. The main diagonal of the matrix is a percentage indicator of class distinction, and the other positions are indicators of overlap or similarity. The row labelled "unclassified" refers to pixels whose intensity vectors are considerably different from those of the nearest class. In the unsupervised approach, these pixels are nevertheless classified, by being placed into the class they most resemble, unless

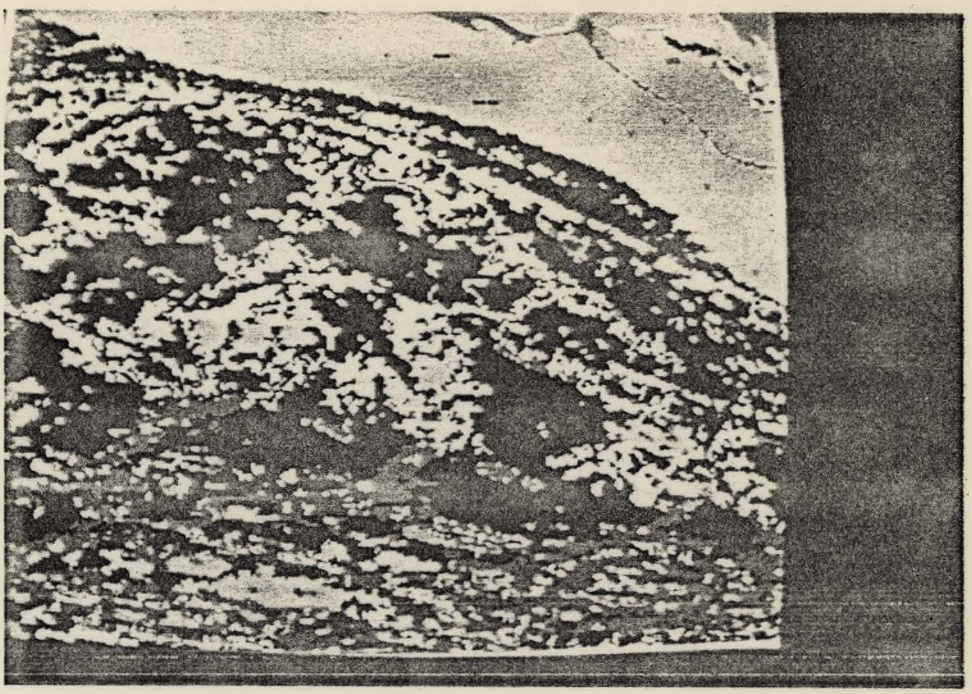


Figure 5.11 Classified scene displayed in Figure 5.10 reproduced with a 3x3 weak filter

Figure 5.12 Classified scene displayed in Figure 5.10 reproduced with a 3x3 strong filter

TABLE 5.III

MEAN REFLECTANCE VALUES FOR CLASSES

DISPLAYED IN UNSUPERVISED CLASSIFICATION (FIGURES 5.10&5.14)

Class	Colour	Band 4	Band 5	Band 6	Band 7
1	Bright Green	17.4	14.4	25.3	17.1
2	Dark Purple	18.9	17.7	25.2	17.0
3	Dark Green	20.1	19.5	30.4	21.7
4	Blue	16.4	13.2	13.8	5.1
5	Turquoise	23.0	17.9	12.0	2.4
6	Orange	26.2	27.9	29.0	14.7
7	White	21.2	20.7	27.9	18.2
8	Pink	19.9	19.0	28.1	20.0
9	Dark Red	18.8	16.9	28.7	20.8
10	Light Purple	17.8	14.8	28.3	20.7
11	Yellow	17.4	15.1	21.6	12.8

TABLE 5.IV

CONFUSION MATRIX FOR UNSUPERVISED

CLASSIFICATION DISPLAYED IN FIGURES 5.10&5.14

	True Class										
"Chosen Class"	1	2	3	4	5	6	7	8	9	10	11
Unclassified	0	0	0	19	19	17	0	0	0	1	0
1	87	2	0	0	0	0	0	0	1	10	5
2	1	78	0	0	0	0	2	1	6	0	4
3	0	1	86	0	0	0	0	2	5	0	0
4	0	0	0	77	0	0	0	0	0	0	0
5	0	0	0	0	81	0	0	0	0	0	0
6	0	0	0	0	0	82	0	0	0	0	0
7	0	3	0	0	0	1	94	8	0	0	0
8	0	4	10	0	0	0	4	83	5	0	0
9	1	8	4	0	0	0	0	6	79	9	0
10	8	0	0	0	0	0	0	0	4	80	0
11	3	4	0	4	0	0	0	0	0	0	91

For identification of classes, see Table 5.III.

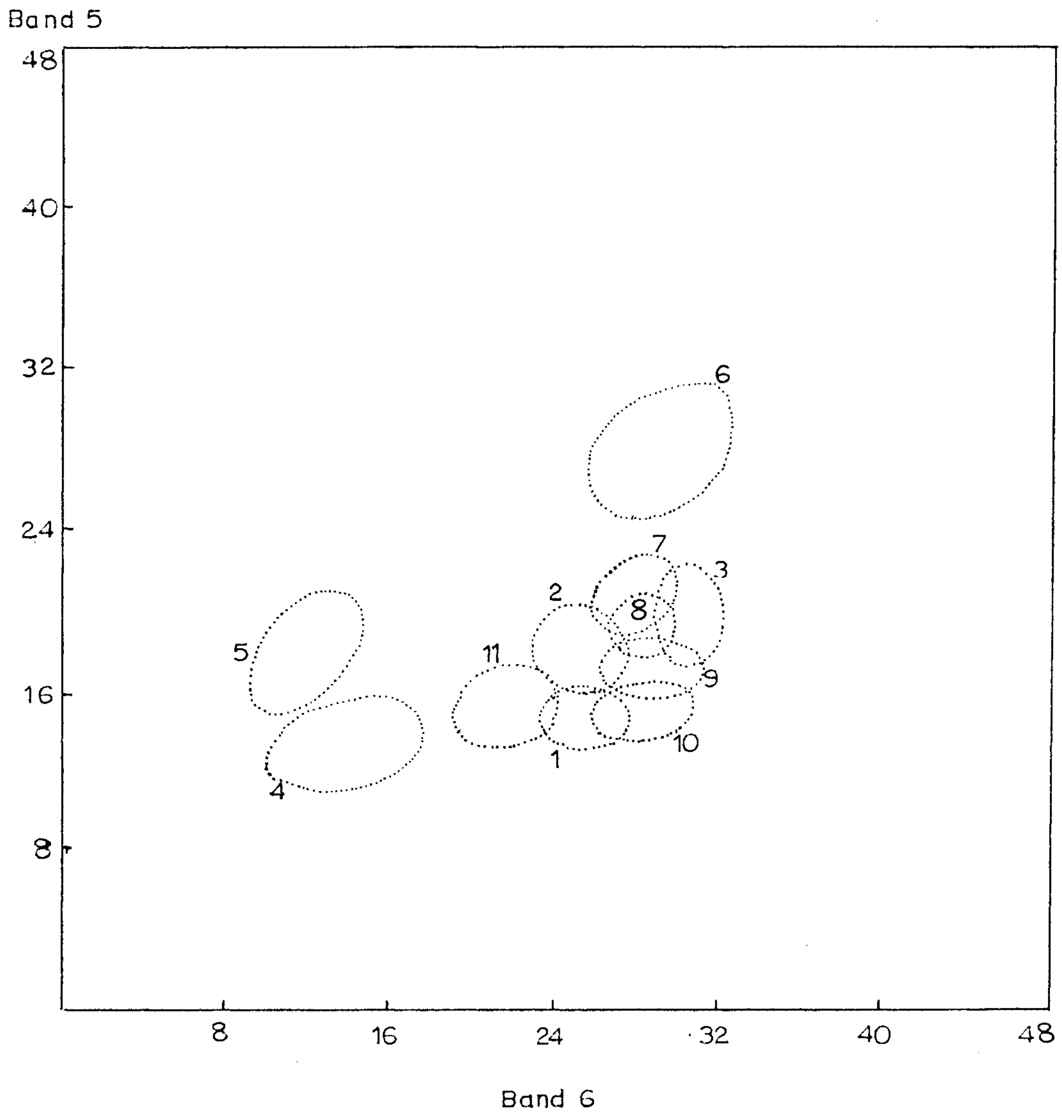


Figure 5.13 Projection plot of Band 5 versus Band 6 for decision regions of unsupervised classification. Numbers refer to classes in Table 5.III.

they are radically different.

Although the confusion matrix is intended for use in the supervised classification where the "true" or known class of the training pixel is compared to its "chosen" or spectral class, it may also be employed in a qualitative sense in the unsupervised method. In this case where there is no "true" class, the confusion matrix is related to the statistical characteristics of the intensity vectors (Howarth, 1976).

Once the image and statistics had been analyzed and the results deemed satisfactory, the classification data were recorded on a computer tape. From this, an EBIR print of the final unsupervised classification of the Pen Island area was generated. Figure 5.14 illustrates this version of Figure 5.10.

b) Results

The final unsupervised classification shown in Figure 5.14 is very similar to the visual analysis of the LANDSAT imagery and the interpretation of the aerial photography. Table 6.I correlates the classes identified by the unsupervised method with those of the earlier analyses. The similarity indicates that the digital technique has produced a map of landscape types at Pen Island. Each of the classes is described below:

1) Bright Green The class depicted as bright green in Figure 5.14 corresponds well with Class 4E, the spruce forest and peat plateaus, and Class 4F, the shrub-covered sedge meadows. At an intermediary stage in the digital analysis, it was divided into two classes, shown in Figure 5.8 as medium blue and bright green. These

Figure 5.14 Final unsupervised classification produced via EBIR for Pen Island scene displayed in Figure 5.3

did not differentiate classes 4E and 4F, however, and their reflectance patterns were similar. They have, therefore, been combined in the final classification.

The low reflectance values of this class, compared with those of other vegetated surfaces, imply that the conifers are important in making it distinctive. Parts of 4E and 4F that have been omitted include, respectively, areas where the coniferous crown is very open, and areas where the shrubbery is nearly all deciduous. Generally, such pixels are located beside rivers where many different surfaces occur over a short distance. The intensity vectors may combine two surfaces, or they may be affected by isolated clumps of spruce.

2) Dark Purple Class 3A and the sedge meadow of the previous analyses are equivalent to the dark purple image in Figure 5.14. This category is distinguished by intensity vectors which combine the spectral characteristics of water and vegetation.

Peripheral areas of the sedge meadow tend to be excluded from this class. This is the case near the spruce forest, where the two vegetation types often intermingle, and also near the lakes (blue) and the lichen heath (white), where the proportion of water to vegetation recorded for each pixel often decreases. An opposite situation exists in very wet areas, where the ratio increases enough to create a separate class. As with the first category, there are a few pixels along the rivers that are wrongly included in this class. These are thought to cover part of the river and part of its vegetated banks, yielding intensity vectors that simulate those of the sedge meadow.

3) Dark Green Separated from other vegetated areas by its high reflectance values in all bands, this class unites the young salt-marsh (Class 4B) and the transitional marsh (Class 4D). Efforts to classify the two communities individually were unsuccessful.

While some parts of the young and transitional marshes are left out of the dark green class, there are many areas included that should not be. These are invariably tied to the river channels in the treeless landscape near the coast. Generally, they denote riverine grasses and willows that are extensive enough to affect the MSS record. The largest area, however, located in the upper centre of Figure 5.14, cannot be explained form photo observation in which it appears to be a peat meadow.

4) Blue This class is very distinctive due to its low reflectance characteristics in the near infrared. It compares with clear-water sites on the aerial photography and LANDSAT imagery. Being easily separated from other classes, very few pixels are incorrectly included in or omitted from this class.

5) Turquoise Corresponding to Class 1A of the earlier LANDSAT analysis and representing turbid water are the turquoise areas in Figure 5.14. The reflectance characteristics of this class show the lightening effects of the suspended sediment load on the visible wavelengths. As with Class 4 above, this one has very little confusion with other classes.

6) Orange The tidal flats (Class 2A) and the areas of bare sand (Class 2B) are coloured orange in Figure 5.14. The spectral values of this class are high in all bands, making it unlike the

classes representing water or vegetation. No attempt was made to separate the two component landscapes, although this step most likely could have been carried out successfully. While little error is apparent in the combined category, there are a few wrongly classified pixels over the tidal flats. These pixels occur as drop-outs in the record of the original data and are visible in the unclassified scene as well.

7) <u>White</u> White areas in Figure 5.14 are analogous to Classes 3B and 3C, the lichen heath and the spruce-lichen woodland, and also the old burn. Although each of these landscapes has a variety of plants, they all have a ground cover of predominantly lichen and therefore have a unique pattern of spectral reflectance.

It is quite surprising that this category is as well defined as it is, since it is comprised of very narrow ridges. The linear continuity of these features is important in their detection. Nevertheless, there are several areas known to be lichen heath or spruce-lichen woodland that are not identified. Some of these areas fall below the resolution of the sensing system, while others have large enough amounts of non-lichen vegetation to change the characteristics of their intensity vectors. Also excluded are numerous small areas scattered along most of the ridges. Commonly only a few pixels in size, these are considered to be boundary situations where one pixel covers two adjacent landscapes. One major misclassification is present in this category, that being the narrow strip of white located along the saltmarsh-tidal flat interface. This is a zone of bare ground with a scant and discontinuous growth of vegetation. Reflectance values recorded by the LANDSAT MSS integrate the two surfaces to create intensity vectors that approach those of the lichen landscapes.

8) Pink Predominantly pink areas in Figure 5.14 identify Class 4A,the peat meadow, of the previous interpretations. The general distribution of this class is similar to, but somewhat more extensive than, that of the earlier work. At the local level, however, there are a number of difficulties, as may be inferred from the mean reflectance values which occupy the middle of the range covered by the vegetated classes.

Areas of peat meadow not designated as pink in Figure 5.14 are small but plentiful, and are not boundary locations. Usually they are dark green or dark red, the colours representing saltmarsh and riverine communities. Close examination of the aerial photography indicates that these areas tend to be small tributary drainage channels whose presence is revealed by a change in vegetation and reddening of the photo image. Wrongly classified as pink are many marginal parts of the sedge meadows, where there is often a transitional zone between the sedge and the peat landscapes. This is especially the case along the left side and through the middle of Figure 5.14. The section of the leading relic ridge, between the camp and the river mouth, is also placed in this category, as it is younger than the rest of the relic ridge complex and has fewer lichens present.

9) Dark Red This colour largely represents a saltmarsh community that is not separately identified in the previous analyses but is apparent on the photography. It designates the upper part of the young saltmarsh, as well as many marginal parts of the mature

saltmarsh. The spectral characteristics of this class seem to approach those of the mature saltmarsh (Class 10), but they also bear some resemblance to those of the young saltmarsh (Class 3).

Pixels belonging to the dark red class but not signifying saltmarsh depict the small drainage routes in the peat meadow and the sedge meadow-spruce forest interface. They also show areas of riverine vegetation in the treeless landscape near the coast. In each case, these are areas of relatively lush growth which are spectrally similar to the saltmarsh.

10) Light Purple The majority of the mature saltmarsh is delineated by this class. Its reflectance characteristics typify a surface with a rich growth of herbaceous plants, making it different than most other vegetated classes. Part of the mature saltmarsh is included in Class 8, however, and it is suggested that a better classification may be achieved if the three saltmarsh classes, numbered 3, 9 and 10, were combined and then divided. This would yield somewhat different groupings, as the three existing ones are not derived from the same original class.

Non-saltmarsh communities included in Class 10 are small in size, and are better seen in Figure 5.8 where they are yellow. These pixels reveal areas along the larger streams in the wooded zone, that support a growth of tall, thick willow shrubs, as well as areas where the spruce forest and sedge meadows blend together.

11) Yellow This final category in the unsupervised classification was not mapped in the airphoto interpretation but was delimited in part in the visual LANDSAT analysis. There it was

labelled Class 4G, an area of older sedge meadow thought to contain many coniferous trees and shrubs. In the digital analysis, 4G is combined with large areas known from photo and field observation to be very wet sedge meadow. These are surfaces of nearly all water with only a small proportion of vegetation. The reflectance values of Class 11 fall somewhere between those of Class 2, the sedge meadow, and Class 4, the clear water, also indicating the increased amount of surface water in this class. At the same time, they broadly resemble those of Class 1, the spruce forest, implying that the suggested nature of Class 4G may be correct.

Spectrally, the yellow class of Figure 5.14 is quite distinct and there appear to be very few areas of wet sedge that have been excluded. There are, however, several pixels placed in this class that are not wet sedge. These are especially apparent in Figure 5.8 where they are coloured pink. Their location beside lakes and rivers reveals that they are boundary pixels which combine plant and water reflectances and thereby simulate the very wet sedge meadow.

The confusion matrix (Table 5.IV) for the final unsupervised classification of the Pen Island site shows that the 11 classes are spectrally distinct, there being no significant overlap among any of them. Classes 4, 5 and 6, the water and bare ground classes, are characterized by several unclassified pixels, whereas the remaining vegetation classes have virtually none. Unlike the original vegetation class in Figure 5.5, the water and bare ground ones were not subdivided. They have, therefore, a wide variety of intensity vectors within, some of which are quite unlike the means.

The confusion matrix points out some discrepancies among the classes that were not detected in the evaluation of Figure 5.14. The complexity of this scene made it impossible to locate all areas of difficulty. Confusion of Class 11 (very wet sedge meadow) with Class 2 (sedge meadow) and Class 4 (clear water) is quite logical, but it had not been noticed. Nor had the confusion along the borders of similar classes always been apparent, yet re-examination of the classified scene indicates that this type of discrepancy may be quite sizable. This is particularly the case with Classes 3, 9 and 10, the different saltmarsh classes, and with Classes 2 and 8, the sedge meadow and the peat meadow.

Observations of Figure 5.14 and the confusion matrix regarding class separability are further supported by the plot of the decision ellipses using Bands 5 and 6 (Figure 5.13). The water and bare ground classes, numbers 4, 5 and 6, again show the greatest distinction, while the vegetation classes are more similar. They are separable, but do have some overlap. Class 8, the peat meadow, has the largest amount of overlap and would appear to be poorly distinguished, but in reality it is not. Since the confusion matrix shows that Class 8 has good separation, Bands 4 and 7 of the LANDSAT data, not used in the projection plot, must contain additional information that makes it more recognizable. It is interesting to note that the ellipse for Class 11, the very wet sedge meadow in the main, approaches the ellipses for water, as had been suggested by the interpretation of Figure 5.14.

c) Discussion

The unsupervised classification of the digital LANDSAT data for

Pen Island by means of the Bendix Multispectral Analyzer Display System was easily carried out and required relatively little time. To give significant results, however, the classification needed a reliable input of information from the user. The subdivision and recombining of classes at various stages in the procedure necessitated an intimate familiarity with the area under study. Even with such knowledge, two sessions on the MAD were required to produce the final classification, the detailed examination in between revealing where modifications were needed. Continued study of the classified image has suggested that yet another alteration could be made. Thus, while termed unsupervised, this approach to digital analysis cannot be carried out successfully without specific ground information. The user cannot simply feed an unknown area into the system and come up with the answers he desires.

Analysis of the LANDSAT data recorded on July 22 using the unsupervised digital technique has produced excellent results over the Pen Island area. The classes and their distributions correspond well with those of the preceding analyses. As can be seen in Table 6.I, the site under investigation is divided into 11 classes in the unsupervised classification, compared with 15 in the visual analysis of the LANDSAT data and 19 in the examination of the aerial photography. These discrepancies are largely explained by the combining of classes on the photography that are spectrally quite similar on the LANDSAT data. Thus, the bare sand and mudflats were grouped together in the unsupervised classification, as were the three lichen surfaces (the heath, the woodland and the old burn), and the peat plateaus, the spruce forest and the shrub-covered older sedge meadow. Although some of these component classes could be distinguished visually on the LANDSAT imagery, digital recognition was not possible, except, perhaps, for the bare ground class. This arises directly from the nature of the vegetation, and results in a loss of some biophysical information. The combined categories do, however, convey more general landscape ideas: the lichen surfaces are all dry upland sites on sandy relic beach ridges, while the last group are all older wetland sites with silty clay material and coniferous vegetation.

The saltmarsh at Pen Island presented some difficulty in the digital analysis. The unsupervised technique identified the mature saltmarsh, but it did not separate the young saltmarsh from the transitional marsh, and it generated a third class that included parts of the young and transitional marshes adjacent to the mature saltmarsh, as well as some marginal areas of the mature community. As the three digital classes are not derived from one class, an improved classification might be achieved if they were to be combined and then redivided.

Boundary pixels, those that cover two different surfaces where they meet or those that cover a transitional zone between the two, are a frequent source of speckling in the classified scene (Figure 5.14). These pixels record a combined spectral reflectance, and are often grouped with neither of the two surfaces but are recognized as a third. This is particularly the case with the pixels along the rivers, which often cover vegetation and water, and also near the spruce (either forest or peat plateau) -sedge meadow interface, where the two surfaces blend together.

The various statistics generated in the digital analysis played a helpful role in the evaluation of the final classified scene. The spectral reflectance characteristics for each class were compared with known spectral signatures and then used to determine what the different classes represented and why certain areas were classified as they were. The confusion matrix proved to be a very valuable table of information even though it could only be used qualitatively. It revealed precisely where the spectral similarities occurred. Sometimes these overlaps were not noticed, and frequently they were difficult to see simply by visual examination of the classified image. Also of use in assessing the results were the projection plots of the decision ellipses. These lent further support to observations made of the classified scene and the tables of statistics.

The filtered versions of the final classified image, produced to minimize the effect of the boundary pixels and other anomolous ones, provided further aid in the analysis of the unsupervised classification. The 3x3 strong filter presented a good generalization for most landscapes (Figure 5.12), while the 3x3 weak filter gave a somewhat more detailed but still tidied view of the original classified scene (Figure 5.11). Both were useful in that they revealed the main pattern of landscapes very clearly. However, they removed considerable amounts of the narrow linear features (white). This is especially so with the strong filter. Nevertheless, this writer found it helpful to study the weakly filtered image in conjunction with the unfiltered one, in order to evaluate the classification. Such a procedure allowed the main pattern of classes to be learned and then the finer detail to be examined.

Based on the findings presented in this discussion, it is suggested that the evaluation of an unsupervised classification should consider the image in original and filtered form, the reflectance values, the confusion matrix and the projection plots all at once. The filtered version can provide a basic familiarization with the distribution of the different classes, and the statistical and graphical data can point out particular features that require investigation on the original image. At the same time, that image must be examined in its own right, since not all problems are revealed by the other types of output. All of this work must be carried out in conjunction with some form of ground information, be it aerial photographs, maps, airphoto interpretations or field studies. In this way, the classes can be identified as well as detected and delineated.

One final point to note in the unsupervised classification relates to the type of output. The photograph from the MAD television monitor is valuable, in that it is easily and cheaply obtained and is in a convenient size for handling. However, its colour rendition is not always good. In the series of illustrations from Figures 5.7 to 5.10, the turbid water in the upper right is barely different than the clear water of the lakes, yet on the monitor these were very distinct. Also, small areas a few pixels in size often lose their colour on the photographs and show up white, as do class boundaries. Neither of Figures 5.8 or 5.9 should have any areas coloured white. The problem is very marked in the lower third of the final classified scene (Figure 5.10), almost none of which is actually white. The image on the TV monitor also contains some vertical squeezing, which sometimes makes checking with ground data difficult. Comparison of the photograph from the MAD (Figure 5.10) with the EBIR output (Figure 5.14) indicates that the latter is clearly a much better image in terms of colour. Yet, the EBIR print requires at least a month for production, and the expenses of tapes and processing must be added. For the Pen Island area and likely most others, the limitations of the photograph from the MAD TV screen can be overcome by referring back to photographs of intermediary stages, which are less complex.

5.4.3 Supervised Classification of the Pen Island Site

a) Procedure

The scene used in the visual and unsupervised classifications was again selected for the supervised digital analysis. By examination of the airphoto interpretation and the visual LANDSAT analysis, training areas were chosen that would give relatively large samples for each type of landscape. Initially 14 different classes were involved in the training procedure. Their intensity vectors were analyzed and the results were applied to the entire scene. Figure 5.15 is an image of the first supervised classification of the Pen Island site.

The broad pattern of landscapes apparent on the original unclassified scene (Figure 5.3) is also visible in this illustration. Clearly, however, many of the classes require modification. The most readily apparent problem lies in the confusion between the lichen heath (light blue) and the sedge meadow (purple).

In an attempt to improve the precision of Figure 5.15, areas that were incorrectly classified were used as training areas to

Figure 5.15 Initial supervised classification with 14 classes for Pen Island scene displayed in Figure 5.3

enlarge the existing training classes. With the heath class, the easiest procedure was to train the computer to recognize the incorrect areas as sedge, and then delete the training information for the old heath class and then redefine it. The results are displayed in Figure 5.16. In this newly classified image,the sedge meadow versus lichen heath problem is largely solved, although there are still some small areas wrongly classified. With this clarification of the image, many other less sizable errors in the classification are visible.

Modification of Figure 5.16 included the deletion of the class intended to show the grass and willow vegetation of the floodplains along the rivers. This class was so small that it could not be seen on the television monitor. The classification was thus reduced from 14 classes to 13. Additional training for the sedge meadow class was carried out to eliminate those areas classified as lichen heath. As a final step, the colour of one of the classes was changed to make it more distinguishable. The product of these changes, seen in Figure 5.17, does not vary much from Figure 5.16. The elimination of the willow class and the retraining of the sedge meadow class caused no noticeable change. It is of interest to note that the colour selected for the indistinct class was not one of the 15 specified in the programme, but was one of the 32 available in the MAD system. The colour was not recognized by the programme and as a result, the class appears black in the classified image (Figure 5.17). Although it is now easily seen,the colour of the class must be changed, since black signifies pixels that are too different from any of the classes to be classified. Several of these are apparent near the

Figure 5.16 Modified version of Figure 5.15 with improved sedge-heath separation

Figure 5.17 Modified version of Figure 5.16 with reduction to 13 classes

top of the Figure 5.17.

At this point in the classification process, it was realized that the misclassified pixels in the sedge meadow were being confused with classes denoting the relic beach ridges. These narrow, often diagonally linear features were difficult to train upon, and it was thought that the training sites may have included parts of the sedge meadow. To overcome this suspected problem, the end pixels of each training area in the lichen heath (light blue) and spruce-lichen woodland (orange) classes were temporarily deleted, but the original data were stored in the system, in case the overlap was not the source of confusion. An acceptable colour was assigned to the class left black in Figure 5.17, and then a revised classification of the area of study was generated (Figure 5.18). Examination of this image indicates that the new colour is a poor one, overpowering adjacent classes in many areas, particularly the medium green class (Figures 5.17 versus 5.18). The chopping procedure is also unsuccessful. Rather than tidying up the sedge meadow class (dark purple) and eliminating the discrepancies, it has merely removed much of the lichen heath and spruce-lichen woodland classes that were previously correctly classified.

Based upon the unsatisfactory nature of Figure 5.18, clearly the best classification attainable for the site under investigation is that appearing in Figure 5.17. Since the statistics from its generation had been saved, they could be recalled in their original state, bypassing the modifications introduced in Figure 5.18. Some colour changes were applied to the data, and the result is the final supervised classification for the Pen Island site, Figure 5.19.

Figure 5.18 Unsuccessful attempt to improve class separability in Figure 5.17

Figure 5.19 Final supervised classification produced by MAD system for Pen Island scene displayed in Figure 5.3

As in the unsupervised classification, programmes were run following the generation of Figure 5.19 to produce information that would aid in its evaluation. The mean reflectance values for the pixels in the training classes were obtained (Table 5.V), as were the graphical and statistical data describing the class separability. These included the seven projection plots of the decision ellipses, of which the one for Bands 5 versus 6 features the least overlap and is reproduced in this text (Figure 5.20), and also the confusion matrix (Table 5.VI). In the supervised classification, this table of statistics compares the user-assigned class to the spectrally- or computer-assigned class for the pixels in the training sites. It may be considered in a quantitative sense, the numbers indicating the percentage of pixels assigned to each category. Lastly, an EBIR print of the final classified scene (Figure 5.19) was created, in order to provide an image with better colour rendition. Figure 5.21 presents this improved version of the supervised classification of the Pen Island site.

b) Results

As one may expect, the results of the supervised classification are similar to those of the preceding LANDSAT and airphoto analyses. Reference to Table 6.I reveals the relationships among the classes of each investigation. Assessment of the classified image shown in Figure 5.21 was carried out in conjunction with examination of the other types of output from the MAD system. This work indicated that there were some differences between the supervised classification and the earlier digital and visual analyses. In subsequent paragraphs

TABLE 5.V

MEAN REFLECTANCE VALUES FOR CLASSES

DISPLAYED IN SUPERVISED CLASSIFICATION (FIGURES 5.19&5.21)

Class	Colour	Band 4	Band 5	Band 6	Band 7
1. Water	Blue	22.1	16.6	10.6	2.3
2. Tidal Flats	Grey	26.2	28.2	29.5	15.2
3. Bare Sand	Yellow	30.6	33.6	35.8	22.8
4. Peat Meadow	Pink	20.2	19.7	28.9	20.6
5. Sedge Meadow	Purple	19.1	18.2	25.0	16.9
6. Spruce-Lichen Woodland	Orange	20.0	18.9	26.8	16.8
7. Old Burn	Brown	21.6	20.1	28.1	17.9
8. Spruce Surfaces	Red	16.9	13.4	25.8	17.1
9. Young Saltmarsh	Dark Green	20.4	20.2	30.5	20.3
10. Mature Saltmarsh	Dark Red	18.3	16.0	30.0	21.9
11. Transitional Marsh	Turquoise	20.1	19.3	29.3	22.6
12. Shrub-covered Sedge Meadow	Bright Green	17.4	14.8	25.8	18.2
13. Lichen Heath	Light Blue	20.8	20.2	27.6	18.3

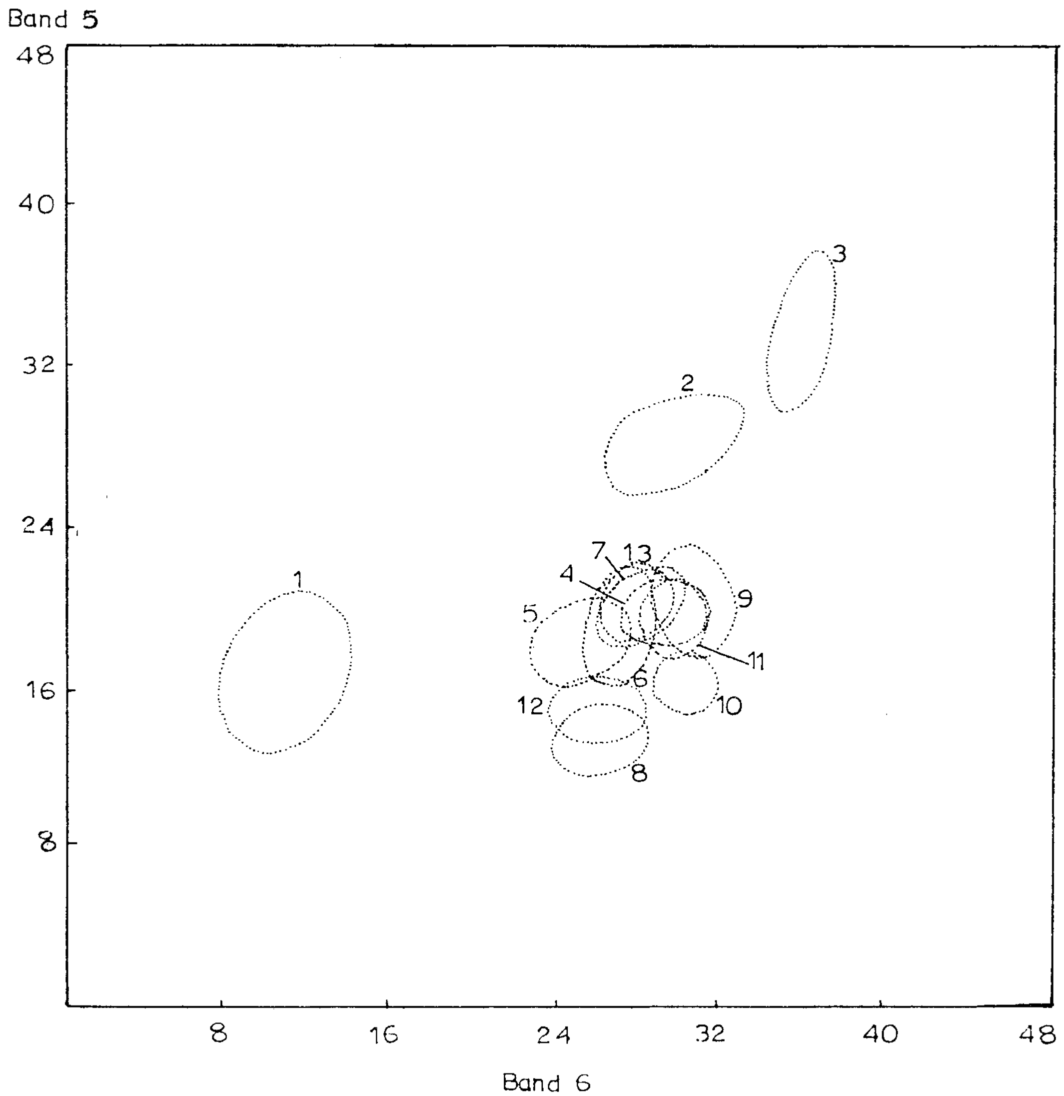


Figure 5.20 Projection plot of Band 5 versus Band 6 for decision regions of supervised classification. Numbers refer to classes in Table 5.V.

TABLE 5.VI

CONFUSION MATRIX FOR SUPERVISED CLASSIFICATION DISPLAYED IN FIGURES 5.19 & 5.21

Chosen Class	True Class												
	Water	Tidal Flat	Sand	Peat Meadow	Sedge Meadow	Sp-Lich Woods	Old Burn	Spruce Surf's	Young Saltmarsh	Mature Saltmarsh	Transitional Saltmarsh	Shrub Sedge	Lichen Heath
Unclassified	1	3	0	0	0	0	0	0	0	0	0	0	0
Water	99	0	0	0	0	0	0	0	0	0	0	0	0
Tidal Flat	0	96	0	0	0	0	0	0	0	0	0	0	0
Sand	0	0	96	0	0	0	0	0	0	0	0	0	0
Peat Meadow	0	0	2	82	7	0	0	0	9	0	9	0	6
Sedge Meadow	0	0	0	2	72	5	2	0	0	0	0	0	6
Spruce-Lichen Woods	0	0	0	0	8	67	6	0	1	0	0	2	8
Old Burn	0	0	0	1	2	13	88	1	0	0	0	0	11
Spruce Surfaces	0	0	0	0	0	1	0	86	0	0	0	16	0
Young Saltmarsh	0	1	1	8	0	1	0	0	78	1	0	0	2
Mature Saltmarsh	0	0	0	0	0	0	0	1	3	98	3	0	0
Transitional Saltmarsh	0	0	1	7	0	0	0	0	0	0	88	0	0
Shrub-Sedge	0	0	0	0	1	0	0	12	0	1	0	82	0
Lichen Heath	0	0	0	0	10	13	4	0	9	0	0	0	67

Figure 5.21 Final supervised classification produced via EBIR for Pen Island scene displayed in Figure 5.3

these differences are described along with the various classes identified in the supervised approach.

The classes representing water and bare ground have been divided in a different way in the supervised analysis when compared with the unsupervised one. Class 1 (blue) in Figure 5.21 combines both clear and turbid water bodies, in order to leave available as many classes as possible for the land surface. The supervised technique allows only 15 classes to be displayed on the monitor at one time. Bare ground, on the other hand, has been separated into two classes, tidal flats (grey) and bare sand (yellow), as this subdivision had not previously been tried on the MAD. The area covered by the water and bare ground classes in Figure 5.21 is like that of the earlier classifications. According to the graphs and statistics related to this scene, the three categories are all very distinctive and experience almost no confusion among themselves or any other classes. There are, however, some unclassified pixels along the tidal flat-water interface. Coloured black, these boundary pixels are spectrally unlike the members of either class.

The remaining 10 classes all define vegetated landscapes at Pen Island. The confusion matrix and projection plot reveal considerable overlap among these classes, although the percentage of correctly classified pixels remains significantly high in each case. The class depicting the mature saltmarsh (dark red) is unique among the vegetated classes, in that it is the only one displaying almost no interclass confusion. This landscape has a set of reflectance values that does not approach those of the other vegetated surfaces.

While it is spectrally distinct from the other categories, there are a number of pixels wrongly included in this class. These are better seen in Figure 5.17, where they are bright red. As in the unsupervised classification, they are primarily areas of riverine vegetation, sedge meadow-spruce transition, or upper young saltmarsh. The latter misclassification could likely be solved by re-defining the training sites for the mature saltmarsh.

The rest of the categories identified in the supervised classification, which are all distinguishable yet exhibit more overlap than the preceding classes, may be organized into three groups according to their interclass confusion. These include:

i) the peat meadow, the young saltmarsh and the transitional marsh;

ii) the spruce surfaces and the shrub-covered older sedge meadow; and

iii) the lichen heath, the spruce-lichen woodland, the old burn and the sedge meadow.

The limited separability within these three groupings is apparent in the confusion matrix as well as the projection plot of the decision ellipses. It can also be detected in the classified image, where each landscape type contains a number of differently coloured, and therefore classified, pixels.

The peat meadow (pink) in Figure 5.21 has a distribution very similar to that in the unsupervised classification (Figure 5.14), and features the same confusion along its boundaries with the sedge meadow (purple). Both classified scenes display many pixels in the peat meadow that are wrongly identified as young or transitional saltmarsh, although these tend to be somewhat less numerous in the supervised image.

The young saltmarsh (dark green) and the transitional marsh (turquoise) are separable by the supervised technique, yet they were not in the unsupervised analysis. The confusion matrix indicates that there is no overlap between these two classes, but that there are several pixels misclassified as peat meadow or mature saltmarsh. The young saltmarsh also experiences some confusion with the lichen heath class (light blue), notably along its seaward edge where the lichen vegetation cover is discontinuous. All of these errors were identified in the preceding digital analysis as well.

The classes denoting the spruce surfaces (bright red) and the shrub-covered sedge meadow (bright green) overlap considerably, but both are well separated from all other classes. They represent categories 4E and 4F of the visual LANDSAT analysis, respectively. These two classes could not be satisfactorily distinguished from each other in the unsupervised classification, resulting in their combining to form one class in Figure 5.14. In the supervised case the confusion between the two is sizeable, but is not large enough to require that they be joined together.

The lichen heath (light blue) and the spruce-lichen woodland (orange) are much better represented in the supervised classification than in the unsupervised one. In fact, the woodland landscape could not individually be identified by the unsupervised technique. Understandably, however, there is substantial confusion between these two lichen surfaces. The heath class also includes many areas of peat meadow and marginal sedge meadow, while the woodland class contains numerous isolated pixels in the more central parts of the sedge meadow. Both heath and woodland categories exhibit overlap with the old burn, which is also a lichen surface in part. As the latter class is too small to be statistically significant, and is scarcely visible in Figure 5.21, it is suggested that the old burn class be deleted. As its pixels would generally be identified as lichen heath or spruce-lichen woodland, the percentage of correctly classified pixels for these two classes should increase.

Lastly, the sedge meadow (dark purple) in the supervised classification intentionally combines the sedge and wet sedge classes of the earlier analyses, primarily due to the limited number of classes available in this approach. It is reasonably well defined in Figure 5.21, except for the marginal areas which are frequently mistaken for lichen heath or peat meadow. In the more central parts of the sedge meadow, there are many wrongly classified areas only a few pixels in size. Identified as spruce-lichen woodland and sometimes lichen heath, these cause an annoying speckling of the classified image, which cannot be removed by filtering as it can in the unsupervised approach. Attempts to minimize the occurrence of these areas by improving the training information were unsuccessful, indicating that certain parts of the sedge meadow feature vegetation types that more closely resemble those of other classes.

c) Discussion

Using the Bendix Multispectral Analyzer Display system, the supervised classification of the digital LANDSAT data for Pen Island was a longer and more tedious process than the unsupervised classification. The initial training was very time-consuming, since there were many different classes and many training sites for each one. Particularly difficult was the training for the narrow linear classes, notably the lichen heath, spruce-lichen woodland and bare sand. The first classified image typically required substantial modification, which proved to be a lengthy and complicated procedure. Even the changing of colours assigned to the different classes was not easy. As in the unsupervised approach, accurate ground truth was an essential data input for the classification process, both for the selection of suitable training areas and for the alteration of the classified scene.

The final supervised classification produced from the July 22 data has yielded satisfactory results for the Pen Island site. Table 6.I indicates that 13 classes are identified by this procedure, compared with 11 by the unsupervised technique, 15 by the visual analysis of the LANDSAT imagery and 19 by the investigation of the aerial photography. The differences between the unsupervised and supervised results are partly explained by the separation of the young and transitional saltmarshes, the spruce-lichen woodland and the lichen heath, and the spruce surfaces and the shrub-covered older sedge meadow in the latter. Also different in the supervised approach is the combining of the two water classes and the two remaining sedge meadow classes to meet the 15-class limit of this technique for simultaneous display on the TV monitor. Undoubtably these classes could have been separated without difficulty. The supervised classification identifies all but three of the classes recognized in the visual LANDSAT analysis. Two of these are attributed to the combined water and sedge meadow classes. The third is Class 4H of the visual analysis, a class defined by its spectral diversity and therefore understandably not detectable by digital techniques. The major discrepancies between the supervised and airphoto analyses relate to the joining of three sedge meadow classes (the sedge, the wet sedge and the apparently conifer-dominated sedge meadows) and of two spruce-dominated surfaces (the spruce forest and the peat plateaus). While the former may possibly be divided into two or three spectral classes, the latter cannot, due to generally similar vegetation cover and therefore reflectance characteristics.

Allowing for the classes that are combined to meet the 15-class limit for visual display, the landscapes recognized in the Pen Island area but not identified in the supervised classification are spectrally not distinguishable. This is a direct result of the vegetation type in most cases, although the narrow riverine landscapes are not detected as such because their pixels cover two different surfaces. These findings agree with those for the unsupervised classification, indicating some loss of biophysical information in the digital method of analysis.

While the supervised classification of the Pen Island site features more classes than the unsupervised one, it also exhibits more confusion. The image created by supervised techniques clearly has a more speckled appearance, which implies more misclassification.

The greatest confusion appears to be caused by the lichen surfaces, these presenting many wrongly classified pixels among themselves and over many of the other classes, especially the sedge meadow. The filtering process of the unsupervised classification is designed to minimize the effect of these pixels, but unfortunately no such option exists in the supervised type of analysis.

The selection of suitable colours for the different classes was a difficult task in the supervised classification. Only 15 are available, and these frequently do not provide sufficient contrast in the classified image. The three saltmarsh communities are not easily distinguished in Figure 5.21, but when they were assigned more separable colours, then some of the other classes were not clearly defined. Further, different colour combinations in the classified scene create different visual effects. The bright green spruce class and the dark red shrub-covered sedge class are about the same size in Figure 5.16, yet in Figure 5.19 the bright red spruce class appears to be very small in comparison to the bright green shrubby sedge. These difficulties were not significant in the unsupervised classification, where 32 different colours may be employed.

The statistical and graphical data generated for the final supervised classification were useful in its evaluation, as they were in the earlier digital analysis. In particular, they pointed out the type and degree of spectral similarity among the different classes. The confusion matrix for the classified image, which relates to the training sites whose true identities are known, displays overlap among the classes, indicating that the different landscapes at Pen

Island do not have homogeneous surfaces. It is also worthy of note that the mean reflectance values of many of the classes in the supervised classification are similar to those in the unsupervised one, suggesting that, for the Pen Island site and the July 22 data, the supervised and unsupervised techniques produced the same division of the landscape, although each method had certain advantages over the other.

Lastly, the supervised classification has been presented in the form of an EBIR print and a photograph from the television monitor. Both types of output are characterized by the same faults and merits as they were in the previous digital analysis.

5.4.4 Signature File Extension

a) Procedure

To extend the files of the supervised and unsupervised classifications over space, a scene was selected to cover four times the aréa used in their generation but to retain that original area in the upper right quadrant. Illustrated in Figure 5.22, the majority of this extended area had been examined in the airphoto analysis and therefore had a ready body of "ground" information for the evaluation of its classified image.

Initially, the signature file extension was carried out using the supervised data. The resulting classification (Figure 5.23) contained two areas of unidentified (black) pixels, one near the coast at the top of the image, the other further inland near the centre. Comparison with the unclassified LANDSAT image revealed the

Figure 5.22 Extended scene of Pen Island area displayed on MAD system and used in classification by signature file

Figure 5.23 Initial classification by extension of supervised signature files for Pen Island area displayed in Figure 5.22

coastal area to be cloud shadow, the broad patch of yellow designating the main cloud body. The inland zone coincided very closely with the recent burn that is apparent on the aerial photographs.

With the supervised technique of analysis, it is possible to generate new training sites at any time and add these to the existing data. The distinctive nature of the ashen burn surface on the photography implies that it is spectrally unique. Accordingly, the inland unclassified area corresponding with the recent burn site was trained upon using the procedure described earlier in this chapter. The results were then combined with the established training information, and the vegetated old burn class, which was not visible in the classified image, was deleted. Application of the revised data to the extended area produced the classification shown in Figure 5.24. The upper left quadrant of this scene was enlarged to full-screen size (Figure 5.25), as it portrays the same range of landscapes at the same scale as the original supervised classification (Figure 5.19). The unclassified image of this area is depicted in Figure 5.26. Subsequently, the mean reflectance values (Table 5.VII) and the confusion matrix (Table 5.VIII), as well as the projection plots (Figure 5.27), were produced for the entire area, and the EBIR was employed to create a better coloured version of Figure 5.24 (Figure 5.28).

Following the completion of the supervised extension, the procedure was repeated using the files of the unsupervised classification. Classified images were generated for the total extended area (Figure 5.29) and also for the upper left quadrant (Figure 5.30). These scenes contained unclassified pixels, but they could not be

Figure 5.24 Classification by extension of supervised signature files and addition of new class for Pen Island area displayed in Figure 5.22

Figure 5.25 Upper left quadrant of extended supervised classification displayed in Figure 5.24

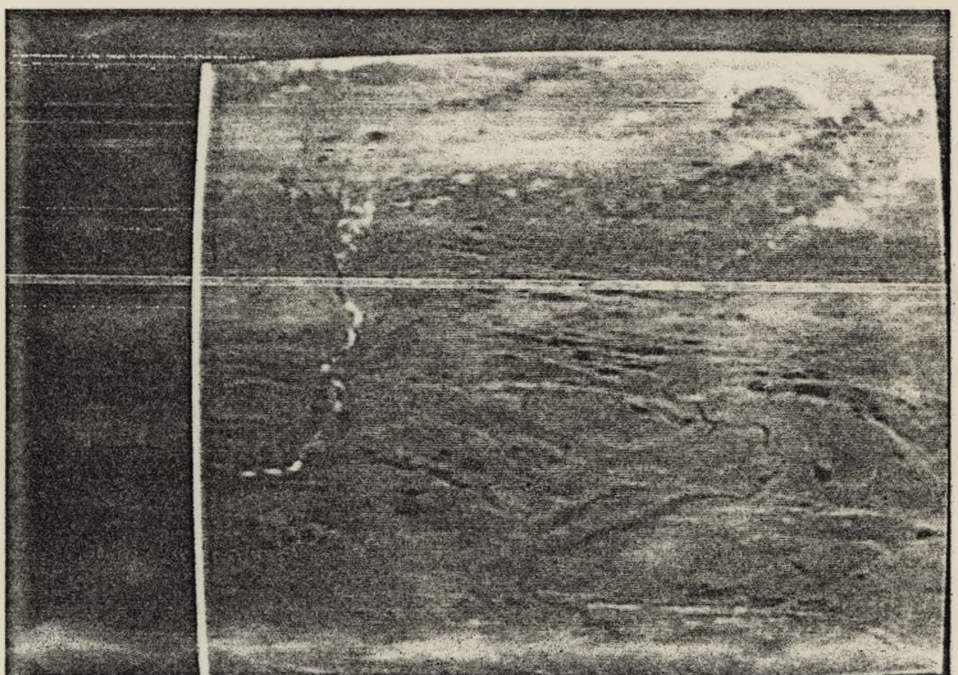


Figure 5.26 Unclassified version of Figure 5.25

TABLE 5.VII

MEAN REFLECTANCE VALUES FOR CLASSES DISPLAYED

IN EXTENSION OF SUPERVISED SIGNATURE FILES (FIGURES 5.24&5.28)

Class	Colour	Band 4	Band 5	Band 6	Band 7
1. Water	Blue	22.1	16.6	10.6	2.3
2. Tidal Flats	Grey	26.2	28.2	29.5	15.2
3. Bare Sand	Yellow	30.6	33.6	35.8	22.8
4. Peat Meadow	Pink	20.2	19.7	28.9	20.6
5. Sedge Meadow	Purple	19.1	18.2	25.0	16.9
6. Spruce-Lichen Woodland	Orange	20.0	18.9	26.8	16.8
7. Spruce Surfaces	Red	16.9	13.4	25.8	17.1
8. Young Saltmarsh	Dark Green	20.4	20.2	30.5	20.3
9. Mature Saltmarsh	Dark Red	18.3	16.0	30.0	21.9
10. Transitional Marsh	Turquoise	20.1	19.3	29.3	22.6
11. Shrub-Covered Sedge Meadow	Bright Green	17.4	14.8	25.8	18.2
12. Lichen Heath	Light Blue	20.8	20.2	27.6	18.3
13. New Burn	Dark Blue	19.8	18.2	21.3	10.6

TABLE 5.VIII

CONFUSION MATRIX FOR EXTENSION OF SUPERVISED SIGNATURE FILES (FIGURES 5.24 & 5.28)

	True Class												
Chosen Class	Water	Tidal Flat	Sand	Peat Meadow	Sedge Meadow	Sp-Lich Woods	Spruce Surf's	Young Saltmarsh	Mature Saltmarsh	Transitional Saltmarsh	Shrub Sedge	Lichen Heath	New Burn
Unclassified	1	3	0	0	0	0	0	0	0	0	0	0	0
Water	99	0	0	0	0	0	0	0	0	0	0	0	0
Tidal Flat	0	96	0	0	0	0	0	2	0	0	0	0	0
Sand	0	0	96	0	0	0	0	0	0	1	0	0	0
Peat Meadow	0	0	2	82	7	0	0	10	0	9	0	5	0
Sedge Meadow	0	0	0	2	73	5	0	0	0	0	1	9	0
Spruce-Lichen Woods	0	0	0	0	9	77	0	2	0	0	0	11	0
Spruce Surfaces	0	0	0	0	0	1	89	0	0	0	13	0	0
Young Saltmarsh	0	1	1	8	0	1	0	75	2	0	0	3	0
Mature Saltmarsh	0	0	0	0	0	0	0	2	93	0	0	0	0
Transitional Saltmarsh	0	0	1	7	0	0	0	3	4	90	0	0	0
Shrub-Sedge	0	0	0	0	1	0	11	0	1	0	86	0	0
Lichen Heath	0	0	0	1	10	16	0	6	0	0	0	72	0
New Burn	0	0	0	0	0	0	0	0	0	0	0	0	100

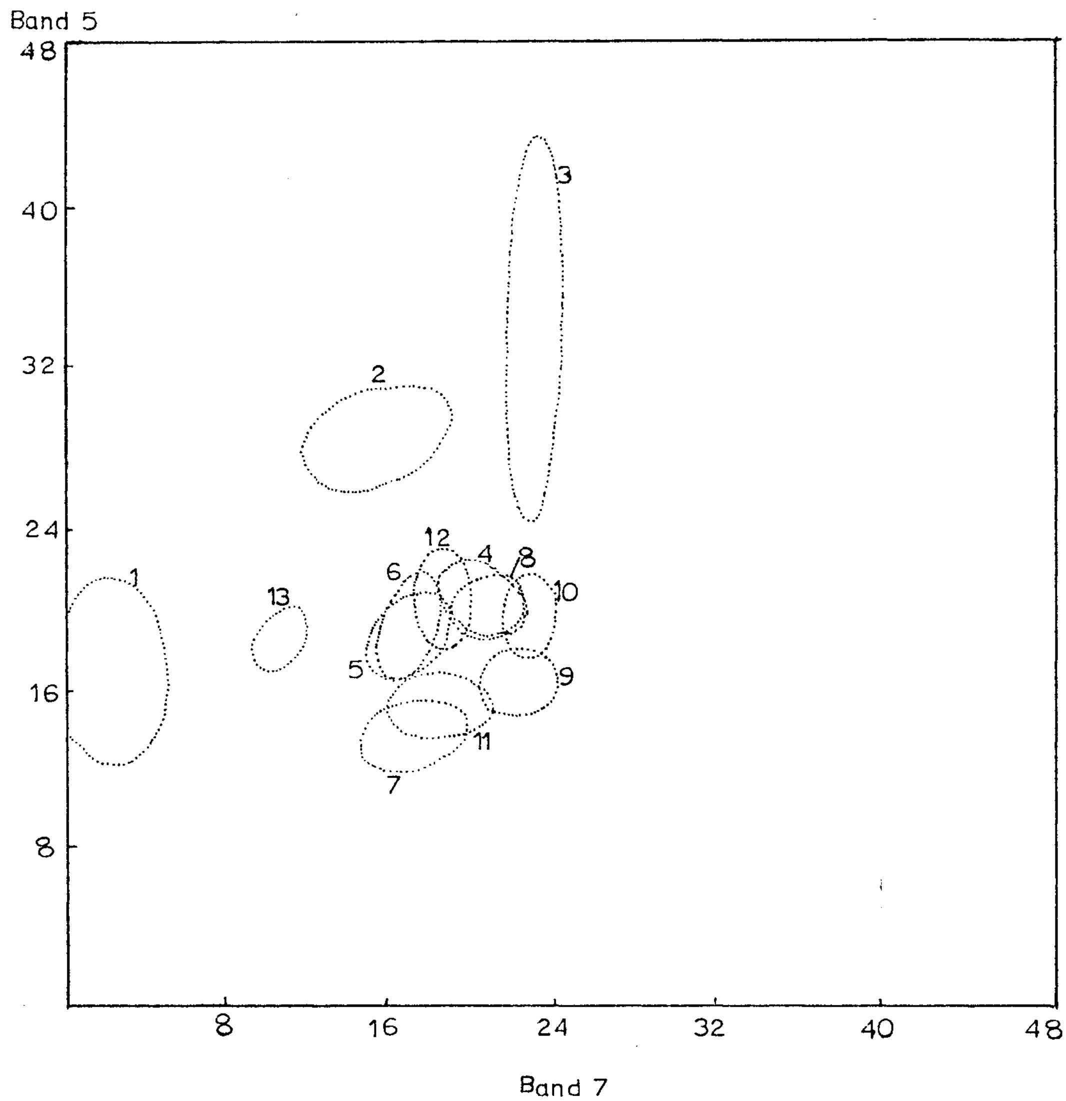


Figure 5.27 Projection plot of Band 5 versus Band 7 for decision regions of extended supervised classification. Numbers refer to classes in Table 5.VII.

Figure 5.28 Extended supervised classification produced via EBIR for Pen Island area displayed in Figure 5.22

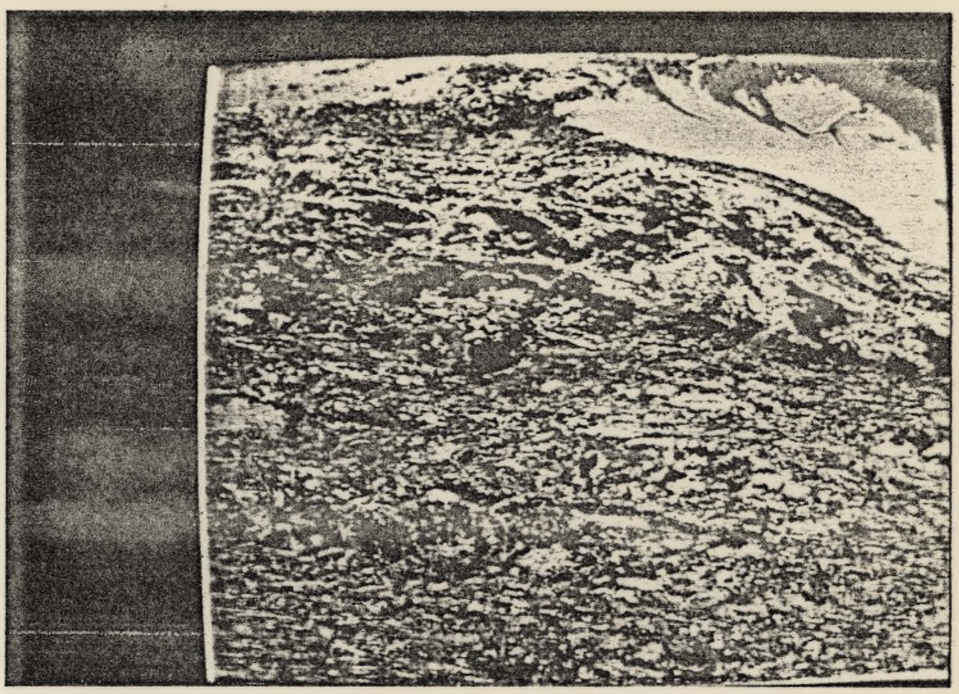


Figure 5.29 Classification by extension of unsupervised signature files for Pen Island area displayed in Figure 5.22

Figure 5.30 Extended unsupervised classification for area displayed in Figure 5.26 (upper left quadrant of Figure 5.29)

modified. The unsupervised technique does not permit further classification in the manner of the supervised analysis. It does, however, permit the classified image to be filtered. Figures 5.31 and 5.32 were produced by applying a weak 3x3 filter to the images in Figures 5.29 and 5.30 respectively. Statistical and graphical data were not generated, as no new classification data had been added to the existing information. The final step involved the creation of an EBIR print of the unsupervised classification over the total extended area (Figure 5.33), for comparison with the preceding supervised one.

b) Results

The extension of the signature files of the supervised and unsupervised classifications have produced generally similar images, both of which have the same class-colour associations as the original classified scenes. These classes tend to delineate the same landscapes over the extended area as they did in the initial site, although there are some differences in the surfaces they represent.

The supervised and unsupervised extensions both contain only two significant areas of unclassified pixels, one relating to the cloud cover, the other representing the recent burn. These are surfaces that are markedly different from those in the original area of study. While no allowances could be made for them in the unsupervised scene, the supervised version permitted the burn to be used as a training site, its reflectance characteristics being added to the existing data and producing an excellent detection of this land type. The statistical and graphical data generated for the

Figure 5.31 Classified scene displayed in Figure 5.29 reproduced with a 3x3 weak filter

Figure 5.32 Classified scene displayed in Figure 5.30 reproduced with a 3x3 weak filter

Figure 5.33 Extended unsupervised classification produced via EBIR for Pen Island area displayed in Figure 5.29

final classified scene indicate its uniqueness among the other classes. The new burn is the only one exhibiting a complete lack of confusion in the training pixels and a classification accuracy of 100 per cent.

The extended classified images demonstrate the detrimental effects of clouds and cloud shadows in digital classification. These anomolous "surfaces" are sometimes placed into one or several existing classes, and other times remain unclassified. In the supervised extension, the clouds are identified as bare sand (yellow), but their shadows are not recognized (black). In the unsupervised case, the clouds and some of the shadows are unclassified (black), but the remaining shadows are shown as a large mixture of classes. The user must be aware of cloud features in the data and allow for these in the analysis of his classified images.

As the extended area covers more of the older landscape than the original scene, it gives a better indication of the classification of the inland lichen surfaces. Comparison of the extended supervised and unsupervised classifications reveals that the spruce-lichen woodland areas are much better defined on the supervised image. They are frequently not identified on the unsupervised one, and there they are included in the class denoting the lichen heath. Many old burn sites are detected in the signature file extensions, being classified by both techniques as lichen heath. The old burn areas are undergoing the regeneration of vegetation and do, in fact, resemble the heath surface. They can, however, generally be distinguished from the heath by their inland location and proximity to the spruce-lichen woodlands.

In the more southerly part of the extended area, the lichen surfaces identified by the digital classifications do not always designate relic ridge sites. This area has been exposed for a longer period of time than the area closer to the coast. Its increased age has led to the development of changing vegetation-landscape associations. This, in turn, causes a number of misclassifications in the digital analyses, particularly with the bog and ridge sites. In the extreme inland areas, the peat plateaus become essentially lichen surfaces, the mosses largely disappearing and the conifers becoming much less common. They have a vegetation cover that is almost identical to the spruce-lichen woodlands of the relic beach ridges. In the supervised classification, they are placed in the lichen woodland class (orange), as well as the lichen heath class (light blue) to a lesser degree. The unsupervised classification, on the other hand, includes them in the pink and white classes, which basically correspond with the peat meadow and lichen heath landscape respectively. As with the spruce-lichen woodlands, recognition of these altered peat plateaus is considerably greater by the supervised technique than by the unsupervised one.

Another difference in the landscape over the extended area is presented by the appearance of palsa bogs in the south. These are classified as sedge meadow in each of the signature file extensions. In the unsupervised classification where the sedge meadow is divided into sedge (purple) and wet sedge (yellow), they are identified by yellow class, and tend to be correctly separated from the adjacent areas of sedge meadow. This division makes the unsupervised classification appear more confusing than the supervised one, but it is a precise and ecologically significant one.

Filtering of the extended unsupervised classification proved to be much more valuable than it was for the original area of study. The smaller scale of the extended image but the same classification detail resulted in a relatively complex scene. The filtering process simplified this image, allowing the distribution patterns of the various classes to be more easily seen.

Lastly, the classifications generated for the upper left quadrant of the extended area are directly comparable with the original classified scenes. They display the same pattern of classes and the same types of errors, indicating that these extensions of the supervised and unsupervised signature files are both very successful.

c) Discussion

The extension of the signature files generated by the supervised and unsupervised procedures yielded fine results for the Pen Island area, permitting the precise and rapid classification of areas beyond the original scene. The time and expense required to classify these additional locations were substantially less than those required to classify the initial area of study. The supervised technique was especially valuable, in that it allowed surfaces similar to those in the original classification to be identified immediately, and surfaces not recognizable to be trained upon and then added to the classified image. This procedure was not possible with the unsupervised method, although classified images generated from this set of files had the advantage of being able to be filtered. Generalization by the filtering process was useful in the extended classification, whose image appeared very complex due to its reduced scale.

In response to the nature of the Hudson Bay Lowlands, the signature file extensions gave better results along the coast than inland from the coast, since the landscapes in the lateral direction are the same as those in the initial area of study. The biophysical nature of these extended areas could readily be learned through the classification produced by the digital LANDSAT analysis and the model developed from the airphoto interpretation. The extension of the signature files to areas further inland gave different but still satisfactory classifications. In these areas the landscape is older, and environmental phenomena do not have the same relationships as they do closer to the coast. The same types of vegetation were detected by digital analysis in the inland areas, but their associations with other aspects of the landscape were often different. There was, therefore, a definite loss of biophysical information. The inland extension of the signature files generated a classification of vegetation rather than landscape types. Yet a generalized picture of the biophysical character of the area was still apparent, relating the vegetation to the drainage conditions: lichen areas denoted relatively dry sites, sedge areas wet sites, and shrub-covered sedge a transition between the two. Further, lichen or shrub classes in a winding and continuous linear form indicated the presence of stream channels.

5.4.5 Principal Components Enhancement

a) Procedure

The original LANDSAT scene selected for digital analysis

(Figure 5.3) is characterized by a number of images that, over the land surface, are primarily grey, red or red-brown. To increase the colour range and thereby improve the separability of these images, the principal components enhancement procedure was applied to the data, following the guidelines described in the HELP files. The resultant image is illustrated in Figure 5.34.

b) Results

The enhancement of the Pen Island scene displays a marked increase in the contrast among the different images over the land surface, making each more easily distinguishable. Whereas most of these were light in tone in the original image and were separable but not overly distinct, they cover a much larger range of tones on the enhanced scene, and are generally very sharply defined. Particularly emphasized are the river channels near the coast (dark blue-green) and the spruce-lichen woodlands further inland (bright white). These landscapes are less clearly seen on the untransformed data, and the rivers could not be identified as a separate class in either of the computer classifications. The enhancement also allows better distinction between the peat meadow (light blue and some yellow) and the sedge meadow (green), and between the older sedge meadow (dark green) and the shrub-covered sedge meadow (medium blue). Besides giving better separation among the different landscapes, the enhancement process has also stressed the variations within each one. Thus, the different landscapes at Pen Island tend to have a more speckled or uneven appearance on the transformed image than on the original one.

Figure 5.34 Principal components enhancement of Pen Island area displayed in Figure 5.3

Not all landscapes experience greater distinction on the enhanced version of the LANDSAT imagery. The three saltmarsh communities are all similar in Figure 5.34, and the spruce surfaces and the rivers in the treeless zone have the same dark blue-green colour. Some parts of the lichen heath (yellow, white) that were recognized in the visual and digital LANDSAT analyses also are not apparent in the enhanced scene, although most of this landscape is more readily identified there.

c) Discussion

The enhanced version of the Pen Island LANDSAT data does not permit more information to be detected than the original image, but it does make the existing information much more easily seen. The general pattern of landscapes can be learned very quickly, although the boundaries are often not as precise, due to the enhancement of variations within the classes as well as between them. The majority of the surfaces feature considerably improved separability on the enhanced image, although there are a few which are better seen on the untransformed data.

The principal components enhancement is the only means of digital analysis that satisfactorily detects the riverine landscapes near the coast at Pen Island,and it generally provides better distinction of the lichen surfaces. It seems that narrow features, which are often hard to see on the original image due to the small range of colours available, and which are often poorly classified by digital means due to the boundary effect previously described, are better detected on the enhanced image. By creating a wider range of colours, the transformation process makes these features stand apart from the surrounding images.

5.5 Summary and Conclusions

Reported in this chapter has been the analysis of the LANDSAT satellite data for the Pen Island area. The discussion has reviewed the nature of this recently-acquired type of remote sensing information, and has described the procedures and results of its investigation using visual and several digital techniques. The products of each type of analysis have been compared, and all have been related to the air-photo interpretation.

LANDSAT data are collected for a given area on the earth's surface once every 18 days by an earth-orbital satellite. This spacecraft, known as LANDSAT, is equipped with a multispectral scanner, which records reflected radiation in four bands from the green to the near-infrared wavelengths. The system integrates the radiation reflected in each band from an area of specified size referred to as a pixel, combines the four quantities to form an intensity vector, and transmits the information to receiving stations on the earth's surface. Subsequently, the data are processed to yield digital recordings on computer compatible tapes or pictorial displays on photographic film or paper.

The initial investigation of the LANDSAT data for Pen Island involved a visual examination of the imagery. Using a colour-composite image which included Bands 4, 5 and 7, a two-times enlargement of the standard 18.5x18.5 cm format proved to be at too small a scale for effective mapping. A digital enlargement of the data, produced by the MAD system, covered most of the area studied in the airphoto analysis and possessed a more desirable scale. Using a photograph of this scene, areas of similar image characteristics were delineated following conventional photo-interpretation procedures, and were then compared to the aerial photography in order to establish their identity.

The results of the visual interpretation of the LANDSAT image are highly satisfactory. The classes correspond very closely with those of the airphoto analysis, with 15 of the 19 classes on the photographs being recognized. The differences are primarily due to the combining of the spruce forest and peat plateau landscapes, both of which have a closed or nearly closed crown of spruce, as well as the narrow riverine areas in their vicinity, on the LANDSAT image. It is significant that, although shape and texture are sometimes helpful, the different classes are distinguished largely on the basis of hue and tone. These spectral qualities are the sole factors employed in the digital classification processes, and their importance here suggests that the computer analysis of the data is a worthwhile and promising endeavor.

The digital analysis of the LANDSAT data for the Pen Island site was carried out by means of the Bendix Multispectral Analyzer Display System. After loading a computer compatible tape of the data into this system, the user interacts with the device through a teletype in order to select an area of study and magnify it to a desired scale, and then divide it into a number of spectrally distinct classes.

The results are displayed on a television screen, with a different colour being assigned to each class. Statistical and graphical descriptions of the classification may be generated, and the image may be processed through the EBIR to produce a scene in the format of the LANDSAT imagery. The actual classification may be derived by unsupervised techniques, where the natural clusterings among all of the intensity vectors over the entire scene are used to identify different classes; or by supervised techniques, where the user trains the system to recognize intensity vectors of a certain value as belonging to a certain class. A third method of analysis is available which enhances rather than classifies the data. It produces a transformation of the original data, in order to spread out the colour space and increase the separability of the different images. The signature files generated in all three of the analyses may be extended beyond the original area of study. They may be applied to the new area to produce an instantaneous classification or transformation of its data.

The unsupervised approach was first employed in the digital analysis of the Pen Island site. It identified 11 of the 19 classes in the airphoto intepretation, although one of the classes almost certainly could have been divided into two. The unsupervised classification groups together the three lichen surfaces, as well as the young saltmarsh and the transitional marsh, and the two spruce surfaces and the shrub-covered sedge meadow. These combinations are attributed to similarities in the vegetation type or spectral properties. Overall, the classification is very pleasing, the classes having good separation in every case. Filtering of the classified image makes the general pattern more apparent, although the unfiltered scene is still required to see local detail and narrow linear features.

Applying the supervised technique to the same area, 13 different classes were identified, these tending to have the same distribution as those in the previous analyses. The supervised classification separates the three lichen surfaces and also the young and transitional saltmarshes, neither of which were achieved by the unsupervised method. It also distinguishes between the spruce surfaces and the shrubby sedge meadow. The supervised technique is limited to 15 classes and colours. If a greater number of these were available, then as many as 16 classes may have been recognized. In addition to the class and colour restrictions, the supervised image cannot be filtered. This is unfortunate in the Pen Island scene, as there are many misclassified areas only a few pixels in size which cause a speckling of the image.

The signature files of the supervised and unsupervised classifications were extended to cover four times the area of the original scene. Both classified all but two surfaces, one being the cloud and cloud shadow, the other being the recent burn. The burn was trained upon and the results incorporated into the supervised classification, giving excellent delineation of this feature. This capability of the supervised method is very useful, allowing areas of known spectral characteristics to be classified without further training and areas of unknown characteristics to be identified and then added to the existing data. The unsupervised procedure lacks this ability, but it does permit the classified image to be filtered, a definite asset when the scale of the extended area is reduced from that of the original. Both the supervised and unsupervised extensions yielded fine classifications of landscapes along the coast, as these are the same as the ones in the initial area, but when the files were extended inland, some difficulties were encountered. The peat plateaus in this area become lichen surfaces with a few scattered spruce, and are therefore classified as spruce-lichen woodland atop relic beach ridges. The sedge meadows also change, evolving into palsa fields, but are still classified as sedge meadow. These problems reveal changing vegetation-landscape relationships in the older areas, and signal the loss of biophysical information. While the visual, unsupervised and supervised analyses in the original area generally identify biophysical units, the inland signature file extensions identify vegetation units.

The enhancement of the image of the original area of study improves the separation among many of the classes by increasing the contrast among them. It is the only means of digital analysis to identify the riverine landscape. The general pattern of images is more easily seen on the transformed image, but the location of boundaries is less quickly determined. The enhancement is considered to be a useful supplement to the other digital techniques of analysis as it may provide additional information, but it still requires visual interpretation.

Having applied a number of techniques of analysis to the LANDSAT data of the Pen Island area, it may be concluded that each method has a number of merits and limitations. The choice of a particular method for a study depends upon many factors, including the type of information required, its areal extent and degree of detail, the time and finances available, and the background knowledge of the investigator.

The visual analysis is cheaply and easily carried out if it is done from the standard imagery available through the National Air Photo Library. In the Pen Island study, this imagery revealed detailed information about landscape types, but it had to be enlarged by digital, as opposed to photographic, means in order to map the detail. Interpretation of the enlarged image gave very fine results and was very easily achieved, the map produced being comparable to the finest level of detail delineated in the airphoto analysis. Some writers may argue that mapping at such a level is not practical from LANDSAT data, but should be done from aerial photography. Yet the costs of obtaining specially flown photography over a sizable area may be very high, and the flying mission may not be completed if weather conditions are unsuitable. As long as there is some ground information available, be it field studies, maps or reconnaissance panchromatic photography, the LANDSAT imagery, with its timeliness, extensiveness and multispectral qualities, has the potential to yield highly satisfactory results.

When the area of study is very large, digital analysis may be more practical than visual interpretation. For the Pen Island site, the computer classifications produced maps at the same level of detail as the visual LANDSAT and airphoto interpretations. The supervised approach is suggested to be the better means of classification if the signature files are to be extended to other areas within the LANDSAT frame. This method alone permits the identification and mapping of additional classes that do not occur in the original area. At the same time, however, the unsupervised technique is easier than the supervised one, and requires less specific knowledge of the area under investigation. It may serve as a useful first step in the digital analysis, allowing the user to become familiar with the spectral characteristics of his area. The enhancement procedure also is worth implementing, as it is a simple and fast operation which may reveal information not detected in the other analyses. Regardless of the method employed, the signature files generated by the digital analysis cannot be extended to another frame of LANDSAT data. This is unfortunate, however the pattern of breakdown or the pattern of training in the original frame may be extended to another, provided the same general surfaces are apparent there.

CHAPTER VI

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

The subarctic environment is a transitional zone between the boreal forests and the Arctic tundra. It is characterized by close relationships among its different environmental parameters, especially the vegetation, geomorphology and drainage. Field investigations in this area are expensive and difficult, due to its vastness and remoteness, as well as its inaccessability. This has led to heavy reliance upon aerial survey techniques for data collection, yet only the traditional methods are generally used. The aim of the thesis has been to evaluate the information content of some of the more recently-acquired techniques of remote sensing for environmental study in this region. In particular, colour infrared photography and LANDSAT satellite data in visual and digital form have been studied. A biophysical approach has been employed in the analysis, as the various aspects of the environment are interrelated. The investigations have been carried out on the mainland opposite Pen Island, located on the southern coast of Hudson Bay in northwestern Ontario. Accessible by aircraft, the area has been the object of intensive field study by biologists and microclimatologists over the past five years.

The literature review has traced the development of the biophysical concept of study from its initial thoughts in 1900 to its widespread and well-defined nature in 1976. The idea stresses the relationships among the biological and physical elements of the environment, not just the elements themselves. Remote sensing is a major source of information for biophysical analysis, the aerial perspective showing all of the elements together at one time. Especially useful in the subarctic is colour infrared photography, which is well suited to detecting differences in vegetation. LANDSAT data are also potentially valuable due to their wide aerial coverage, and are currently being tested in some areas. The Pen Island site has not been examined by means of remote sensing techniques. It does, however, possess a body of highly localized ground information on the plant ecology, which can provide an important input to a programme biophysical mapping.

Additional field investigations were carried out at Pen Island by the author. These involved looking at the area from a geomorphological point of view and learning what the different images on the photography represented. The geomorphological observations revealed that the area is dominated by active and relic coastal forms whose nature is controlled by the low, flat coast and the storm-wave environment. Inland from the modern shoreline, the landscape is one of fossil coastal features that are being modified by other geomorphic processes, including aeolian, periglacial and fluvial types of activity. The active and relic coastal landforms exhibit distinctive conditions of vegetation cover, peat accumulation, parent material, relief and drainage, and these different associations define biophysical units in the landscape. The different images on the photography are indicative of variations in the vegetation, which are in turn related to variations in the physical characteristics.

The airphoto analysis was begun by using the photography and the field studies to develop a suitable biophysical classification scheme for the Pen Island site. Subsequently, the photographs were interpreted by relating the field data to the photography, learning the image characteristics of the different landscapes and then extending the knowledge beyond the area examined in the field. The resultant map provided a very detailed picture of the landscape at Pen Island, lending further support to the usefulness of colour infrared photography in the study of vegetated surfaces. The spectral properties of hue and chroma were important in distinguishing among the different classes, but the spatial properties of texture, shape and pattern were also valuable in many cases. Examining the final product, it became apparent that the local distribution of the landscapes was related to the drainage conditions, while their regional distribution was related to the time since emergence from the sea. Accordingly, spatial and temporal models were created to simplify the complicated appearance of the classification and to make the relationships among the different biophysical units easier to see.

The LANDSAT data selected for the study differed in time by only one day from the aerial photography. The airphoto images and their interpretation, therefore, provided a valuable, near real-time source of "ground" information. Visual analysis of the standard-size LANDSAT image revealed that its information content was very high, but a digital enlargement of the Pen Island site was required to serve as a suitable base for mapping. The interpretation procedure involved delineating areas of similar image characteristics and then comparing these areas to the photography in order to learn their identity. As shown in Table 6.I, which relates the visual LANDSAT classes to the airphoto classes, nearly all of the landscapes recognized on the photography were also detected on the LANDSAT imagery. The only exceptions were the narrow riverine classes and the ones with fairly similar vegetation but different physical characteristics. These had been separated in the airphoto analysis by textural and spatial properties. Hue and chroma, the spectral features of the image, were the primary criteria used in the identification of the different classes, the lower resolution of the satellite data reducing the importance of the other types of image characteristics. These results suggested that the digital analysis had excellent potential for the Pen Island site.

The digital analysis of the same LANDSAT data was carried out using the Bendix Multispectral Analyzer Display system located at CCRS in Ottawa. The system classifies the data according to its spectral characteristics, either by unsupervised procedures, where the natural clusterings of the data are used to identify classes, or by supervised procedures, where training sites selected by the investigator are used to identify classes. Both methods were employed for the Pen Island site, each giving comparable results. These agreed quite closely with

TABLE 6.I

COMPARISON OF CLASSES IDENTIFIED IN DIFFERENT ANALYSES

Landscape Type	Ground Studies	Airphoto Analysis	Visual LANDSAT Analysis	Unsupervised Classification	Supervised Classification
Water-clear	-	-	1B	Blue	Blue
-turbid	-	-	1A	Turquoise	Blue
Tidal flat	-	201	2A	Orange	Grey
Young saltmarsh	7a	202	4B	Dark green-dark red	Dark green
Mature saltmarsh	7b	203	4C	Dark red-light purple	Dark red
Transitional marsh	7c	204	4D	Dark green	Turquoise
Bare sand	1	101	2B	Orange	Yellow
Lichen heath	2	102	3B	White	Light blue
Spruce-lichen woodland	11	103	3C	White	Orange
Recent burn of spruce-lichen woodland	-	104	(outside area of study)		
Old burn	-	105	3C	White	Brown
Peat meadow	4	211	4A	Pink	Pink
Sedge meadow	3	212	3A	Dark purple	Dark purple
Wet sedge meadow	5	212	3A	Yellow	Dark purple
Shrub sedge meadow	10	212	4F	Bright green	Bright green
Coniferous (?) sedge meadow	-	212	4G	Yellow	Dark purple
Peat plateau	12	213	4E	Bright green	Red
Spruce forest	9	214	4E	Bright green	Red
Palsa bog	13	215	(outside area of study)		
Recent burn of spruce forest	-	216	(outside area of study)		
Riverine marsh - tall grass	8	222	4E	Several	Several
Riverine marsh - short grass	6	221	4H	Several	Several

the earlier analyses (Table 6.I). The majority of the biophysical categories were recognized, but again different landscapes with similar vegetation types were grouped together. This was especially the case in the unsupervised method, where there were two classes that could be further divided by the supervised technique but not by the unsupervised one. Thus, the supervised classification permitted more classes to be identified. The unsupervised classification, however, provided a greater range of colours and therefore classes (32 versus 15), was more easily carried out and modified, and also could be filtered. (The latter procedure made the distribution pattern of the classes more readily apparent). In these respects the unsupervised approach was better than the supervised technique of classification.

While the unsupervised and supervised classifications were of fine quality, they covered a relatively small area. The classification data generated in their development were extended beyond the original site to areas further along the coast and further inland. The extension of both the supervised and unsupervised signature files yielded highly satisfactory results, the only problems being the cloud cover and the new burn sites. These features represented a very small portion of the total scene. The supervised version permitted the selection of training data for the new burn and the addition of this information to the existing classification. Such a procedure was not possible with the unsupervised technique. In the direction parallel to the coast the extended classification was particularly good,as the landscapes were similar to those in the original area. The misclassifications in the new areas were the same as those in the initial scene. The inland extension, on the other hand, featured greater misclassification, as the same vegetation surfaces sometimes designated different physical conditions. As a result, the extended classification in this case was considered to be more of a vegetation one than a biophysical one.

The enhancement procedure is a form of digital analysis that transforms the data to spread out the colour range. Applied to the original Pen Island site, the technique produced an image marked by increased contrast among most of the landscapes. Linear features in particular were emphasized, notably the lichen-covered beach ridges and the river networks. These had been less clearly seen in the original scene with its limited colour range, due to their smallness of size and the overpowering effect of the larger adjacent areas. They often were not as well defined in the other methods of digital analysis, and sometimes were not identified at all.

6.2 Conclusions

While conclusions have been presented in each chapter of the thesis, at this point in the investigation it is possible to draw some general conclusions regarding the different types of remote sensing data and the different methods of analysis. It is clear in the following paragraphs that each one has a number of merits as well as limitations, and each has a different role to play in an environmental study.

1) The aerial photography with its relatively small scale and colour infrared film was unquestionably the best type of remote sensing data for detailed biophysical analysis of the Pen Island landscape. A large number of classes was recognized with a high level of precision. They were distinguished by a variety of spectral, textural and spatial characteristics. Due to natural variations within each class and the factor of image density distortion, however, the interpretation process was long and sometimes difficult. Being interpreted by eye, it involved subjective decision-making, especially in the transitional areas.

2) The LANDSAT satellite data of the Pen Island area had a very high information content for biophysical mapping, given their scale and resolution. Visual analysis of the imagery yielded results that were very similar to the airphoto analysis, with classes being recognized primarily by hue and chroma as well as by texture and shape in some cases. While mapping at such a specific land-type level provided valuable information for the analysis of the subsequent digital classifications, it is probably not practical in terms of time or money, as a digital enlargement of the unclassified scene had to be produced through the MAD system in Ottawa. It is suggested that visual interpretation of LANDSAT imagery may be more feasibly carried out at a general or land-system level using the largest-scale imagery available through CCRS (1:250,000).

3) Digital analysis of the LANDSAT data overcomes the subjectivity of the visual analysis, but it uses only spectral characteristics to identify different classes,and cannot always allow

for the variations within each class. Despite these limitations, the digital analyses of the data for Pen Island were highly satisfactory. Each of the different techniques recognized most of the units identified in the airphoto interpretation, the correspondence among the classes often being very close. Unlike the visual LANDSAT analysis, the digital one can easily be carried out at a high level of detail, as the changing of scales is a very simple operation.

4) Three means of digital analysis were employed in the study, the supervised and unsupervised classifications and the principal components enhancement. Based on the findings of the Pen Island study, it is concluded that the supervised and unsupervised classification techniques are equally satisfactory if they are to be derived for a given area and not extended beyond that area. The improved separation and the increased class recognition of the former are counterbalanced by the greater ease, the larger colour and class range and the filtering capabilities of the latter. No matter which method of digital classification is used, the image enhancement is an additional technique of analysis that should be carried out. It is a fast and easy procedure that may reveal valuable supplementary information not apparent in the digital classification.

5) The signature file extension capability of the Bendix system is potentially very valuable if landscapes over a wide area are relatively similar. At Pen Island, the extended classifications were surprisingly precise. In this type of analysis the supervised approach possesses a distinct advantage over the unsupervised method, in that it allows additional classes to be incorporated into the existing

classification files. If the scale is reduced in the extended image, however, the number of classes in the original classification may be too great and may create a very complex image. The most satisfactory extended classifications are achieved at the same scale as the initial area studied, according to the results at Pen Island.

6) For the Pen Island site with its wide variety of landscape types, the ability of the Bendix system to display 15 to 32 classes simultaneously was essential in order to produce a completely classified image. This implies that the Image-100 with its restriction to 8 classes may be a less satisfactory system for analysis of an area like Pen Island. Certain classes would have to remain combined while others were divided, meaning the entire image could not be classified on the monitor at one time.

7) Ground information is a necessary input to any classification, regardless of the type of data or method of analysis being employed. This investigator believes experience in the field to be a valuable asset in the study, providing a basic familiarity with the area and allowing more confidence in the analysis procedure. For the airphoto interpretation, this is the only ground truth that is needed, but for the LANDSAT analysis, the field observations must be translated into a spatial context due to the small scale of the satellite data. This is achieved by an analysis of the aerial photography, but the interpretation as well as the photographs are needed in the satellite investigations, since certain factors revealed in the digital analyses may have been overlooked in the mapping procedure.

8) Lastly, some conclusions can be drawn with regard to the biophysical approach to land classification. For the Pen Island area it was a very useful concept,the surface vegetation faithfully expressing the nature of other environmental parameters. While no difficulties were encountered in the airphoto interpretation, a number of landscapes with similar vegetation and different physical attributes were combined in the digital classifications due to their spectral similarities. These classes were not necessarily wrong. They merely conveyed a more general biophysical relation, namely vegetation-drainage associations. It is conceivable that visual analysis of the digitally classified image may allow the combined classes to be subdivided into their component biophysical units, as non-spectral properties, especially shape, could be used.

The biophysical concept may or may not be suitable for analyses in other locations. The user must have ground information about different environmental phenomena and their interrelationships in the area of study, and he must also understand the capabilities of the remote sensing data and the method of analysis that he has chosen. Equipped with this knowledge, he may decide whether a biophysical or a cover-type classification scheme would yield more satisfactory results.

6.3 Recommendations

At the conclusion of the thesis it is possible to present a number of suggestions for future studies of this type:

1) For digital classification in areas with diversified landscapes the use of the Bendix Multipsectral Analyzer Display system with its large class-display capabilities is strongly recommended. The supervised method of analysis may produce very fine results,but it would be a more valuable procedure if the full range of colours and classes on the MAD were available to it. Also helpful would be the addition of the filtering option to the supervised technique, for the variations inherent in natural surfaces invariably cause some misclassification and speckling of the classified image.

2) For the Pen Island area, it is suggested that the signature file extension be carried out in other areas of the same frame, particularly along the coast where the landscapes are much like those in the initial scene. Extension further inland may be improved if new classes are incorporated into the existing supervised signature files. This process would likely require additional airphoto interpretation to determine the nature of any landscapes not experienced in the original training area.

3) As it has been indicated in the thesis that the nature of the landscape along the coast of Hudson Bay is relatively constant over great distances, it would be interesting to study another frame of LANDSAT data in one of these locations. If the frame were recorded during the same 18-day cycle as the Pen Island frame employed in the thesis, then the image characteristics of the different landscapes should be largely the same. The files from the Pen Island analysis could not be applied to this extended coverage, although the same procedure or pattern of classification should be possible for scenes

differing in time by only one or two days.

4) Analysis of LANDSAT data recorded on another date for Pen Island is recommended as a future investigation. During the search for suitable data for the thesis two sets were found, one dated July 22, 1973 and the other dated October 2, 1973. While the July set was selected for study due to its temporal proximity to the aerial photography that would provide ground information, the October data featured a greater range of images over the landscape. Digital analysis of the October set may allow more biophysical categories to be identified, and may also present improved class separability.

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MAP 1
Pen Island
General Land Types
Scale 1:70,000
river
open water
general land type
10 upland
20 saltwater wetland
21 freshwater wetland
22 riverine wetland

MAP 2

Pen Island
Specific
Biophysical Units

Scale 1:70,000

- river
- open water
- general land type
- specific biophysical unit
- 101 bare sand
- 102 lichen heath
- 103 spruce-lichen woodland
- 104 recent burn of 103
- 105 old burn of 103
- 201 tidal flat
- 202 young saltmarsh
- 203 mature saltmarsh
- 204 transitional marsh
- 211 peat meadow
- 212 sedge meadow
- 213 wooded peat plateau
- 214 spruce forest
- 215 palsa bog
- 216 recent burn of 213
- 221 grasses & short shrubs
- 222 grasses & tall shrubs