VEGETATION CLASSIFICATION AND LANDSAT-BASED ANALYSIS OF PEATLANDS IN THE HAILEYBURY CLAY PLAIN, ONTARIO

R.S.W. BOBBETTE[1]

and

J.K. JEGLUM

FORESTRY CANADA

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ABSTRACT

A LANDSAT-based classification of peatlands in a nine-township area north of New Liskeard, Ontario is described. Three vegetation classifications were evaluated: the Forest Ecosystem Classification (FEC) for the Northern Clay Belt; the Ontario Wetland Classification (OWC); and an Ecological Land Survey (ELS) vegetation classification system.

The use of transparent plastic overlays of the LANDSAT image allowed precise registration with mapped 1:15,840-scale air photos, and objective transfer of training areas to the LANDSAT display monitor. Two seasons of imagery (LANDSAT 3, May 1978, and LANDSAT 2, August 1976) were integrated, and the combination of two signals allowed better discrimination of closely related communities. The use of autocorrelation and training-area classification-confusion tables suggested that classification errors were, for the most part, related to vegetation types that were segments of continua in terms of physiognomy and dominant species. Autocorrelation values from 0.0 to 0.7 and confusion values of 20% or more indicated that the types involved should be reviewed for possible combination or revision.

FEC types could be identified specifically in approximately 65% of the LANDSAT mapping types, whereas distinct OWC and ELS types could be confirmed in 85% of the types. The maximum-likelihood algorithm accurately or acceptably extrapolated 50% of the FEC types and 65% of the merchantable forested OWC and ELS types. Unmerchantable forested types of the latter two classifications were 40% acceptably extrapolated.

RÉSUMÉ

Les auteurs décrivent une classification des terrains humides reposant sur les images Landsat qui a été étudié sur un territoire couvrant neuf cantons situé au nord de New Liskeard (Ontario). Trois classifications de la végétation ont été évaluées: la classification des écosystèmes forestiers (FEC) établie pour la partie nord de la zone argileuse, la classification des terres humides de l'Ontario (OWC) et un système de classification de la végétation du Relevé écologique des terres (ELS).

L'utilisation de transparents plastiques a permis de faire coincider de façon précise les images Landsat avec des photographies aériennes au 1/15 840 cartographiées et de reporter de façon objective les zones-échantillons sur l'écran d'affichage des images Landsat. Les images de deux saisons (Landsat 3, mai 1978, et Landsat 2, août 1976) ont été intégrées; on a constaté que la combinaison de deux signaux permettait une meilleure discrimination des communautés fortement apparentées. D'après les tables

d'autocorrélation et de confusion des zones-échantillons, les erreurs de classification sont en majorité reliées aux types de végétation représentant des segments de continuum sur les plans de la physionomie et des espèces dominantes. Les types pour lesquels on obtient des varleurs de 0,0 à 0,7 pour l'autocorrélation et de 20% et plus pour la confusion devraient être réexaminés en vue d'une combinaison ou d'une révision.

Les types de la FEC ont pu être identifiés de façon précise dans approximativement 65% des types cartographiques Landsat, tandis que les types de l'OWC et de l'ELS ont pu être confirmés dans 85% de ceux-ci. L'algorithme du maximum de vraisemblance a donné une extrapolation exacte ou acceptable de 50% des types de la FEC et de 65% des types forestiers marchands de l'OWC et de l'ELS. Les types forestiers non marchands des deux dernières classifications ont été extrapolés de façon acceptable dans 40% des cas.

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INTRODUCTION

In Ontario there is currently much interest in wetlands and peatlands by numerous interest and user groups -- conservationists, waterfowl and wild- life managers, naturalists, park and reserve planners, peat extractors, com- munity planners, and foresters. The availability of LANDSAT imagery and access to image-analysis systems has stimulated research into the possibility of using these tools for wetland survey, inventory and mapping. The present report describes a research project undertaken in the summer of 1983 to examine the potential for classifying and mapping peatland vegetation and to compare conventional ground-truthing and air-photo analysis techniques with supervised LANDSAT classification.

A review of the literature suggests that with multi-spectral scanner (MSS) data and a pixel size of 59 by 79 m, LANDSAT imagery and its analysis may be most useful in extensive wildland areas as a complement to field work and stereo air-photo interpretation (Endlicher 1982). LANDSAT image analysis alone may be most useful when small-scale, current and low-resolution inter- pretations are required. It offers especially good opportunities for use as a component in multistage sampling and as a method for updating changes (Quenet 1980, Pala 1982). However, Quenet (1980) cautions that "Users who attempt to use it as a replacement for low-level aerial photography or to obtain detailed inventory information will certainly fail."

In a study associated with the United States National Wetlands Inventory, it was concluded that LANDSAT could not provide the desired level of detail without an excessive amount of collateral data (such as aerial photographs) and field work (Nyc and Brooks 1979). Peatland studies in Ontario that have used LANDSAT information include a densitometric analysis of LANDSAT 2 imagery (Boissonneau and Jeglum 1976). This study was conducted in the Hicks Township area northwest of Timmins, in the Northern Clay Section; it concluded that although wetland mapping could be done on a regional level with LANDSAT, this could supercede expert air-photo interpretation only over large areas and/or where it supplied the best, or only, remote-sensing data.

The Hicks Township study area was reported on in considerably more detail by the Ontario Centre for Remote Sensing (OCRS) (Pala 1982). In this instance, the study area was used as an example to illustrate a LANDSAT-based method of peatland inventory. The results indicated that comparison between a classification and testing system extrapolated from LANDSAT data and a tran- sect study based on air photos was successful. This initial assessment was followed by a more exhaustive report (Pala and Boissonneau 1983) that supplied detailed peatland descriptions and related peat depths to the vegetation types that were identified by supervised classification of LANDSAT imagery.

Other research in Ontario includes that of Pala and Boissonneau (1982), who reported on LANDSAT mapping of peatlands in the extensive Hudson Bay Lowland, and emphasized the possibility of revising the LANDSAT classi- fication system as field documentation and analysis progressed. Most recently, OCRS has demonstrated how thematic mapping can be used to assist in stratifying peatlands for more efficient sampling in peatland-resources inventory (Pala 1982, 1984; Riley 1987).

Many of the LANDSAT peatland studies in Ontario have employed the Ontario Wetland Classification (OWC) (Jeglum et al. 1974). The status of peatland site classification for forestry in Ontario was reviewed recently by Jeglum (1985). The present report evaluates how well LANDSAT MSS images can be used to interpret three different systems of vegetation classification, viz., OWC, a Forest Ecosystem Classification (FEC) (Jones et al. 1983), and an Ecological Land Survey (ELS) classification (Anon. 1982a).

STUDY AREA

The study area, with approximate sample site locations and 1:15,840 air-photo coverage, is presented in Figure 1. It is a block of nine townships that center around Harley Township, north of New Liskeard, Ontario. The area,

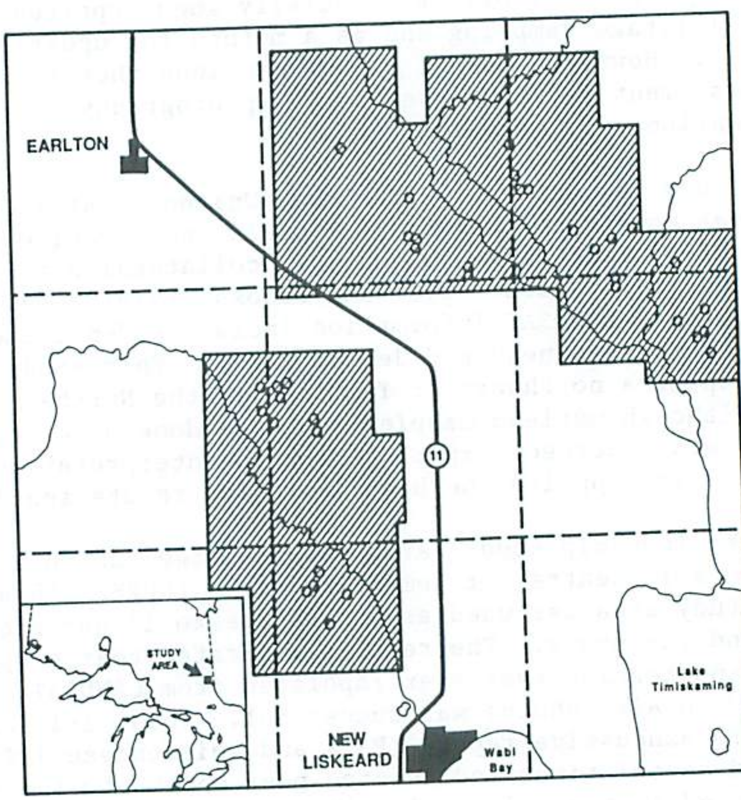

Figure 1. The New Liskeard study area. Cross-hatched areas indicate coverage by stereo, black and white, 1:15,840-scale aerial photographs. Dots are field sites of 30- x 30-m quadrats. The entire area was mapped by means of LANDSAT extrapolation.

which encompasses approximately 900 km^2, was chosen to complement an Ontario Geological Survey (OGS) peatland inventory project (Anon. 1984). All the peatlands investigated were influenced by the extensive drainage and frequent clearing that has been done to facilitate agriculture.

The Haileybury Clay Plain is a northward extension of the Lake Timiskaming valley, and is composed of flat or slightly rolling silty-clay deposits divided by a low ridge of limestone that runs from northwest to southeast (Morton et al. 1979). Peatlands occur in shallow basins with poor drainage as a result of the underlying silty clays. The peats are predominantly woody, are 1 to 3 m in depth, and for the most part have pH values above 4.5. Occasional silt banding probably has resulted from erosion into the peatlands from adjacent short, silt-covered slopes (Anon. 1984).

The Haileybury Clay Plain can be classified as a northern extreme of the Great Lakes-St. Lawrence Forest Region (Rowe 1972) on the basis of local pockets of Laurentian tree species and the general richness of understorey vegetation. These pockets occur mostly near Lake Timiskaming and are, in fact, a minor component of the vegetation, the majority of which is distinctly boreal. Peatland communities are shrub-rich without exception. Dense stands of 20-m-high tamarack (*Larix laricina* [Du Roi] K. Koch) were documented on peat deeper than 2 m. Three of the 36 vegetation samples were classified as treed bog, treed fen and open, low-shrub-rich fen (cf. Jeglum et al. 1974). The majority of stands are dominated by speckled alder (*Alnus rugosa* var. *americana* [Regel] Fern.) and willow (*Salix* spp.) thicket swamps, and mixed-conifer swamps with various mixtures of black spruce (*Picea mariana* [Mill.] B.S.P.), tamarack, and white cedar (*Thuja occidentalis* L.). Glandular birch (*Betula pumila* var. *glandulifera* Regel) thicket swamp is also common.

METHODS

Field

Field data were gathered from 36 quadrats (each 30 by 30 m) that were precisely located on 1:15,840 air photos and tied into survey lines run as part of an OGS Peatland Inventory project (Anon. 1984). An additional 22 general stand descriptions were made.

For all samples, vegetation cover and species composition were described in terms of two tree strata (5-15 m and 15-25 m), three scrub strata (0-0.5 m, 0.5-1.5 m and 1.5-5 m), and herb, bryophyte and lichen strata. Ocular estimates of percent cover were made for each species in each stratum of occurrence.

The nomenclature used for vascular plants follows that of Gleason and Cronquist (1963) and Scoggan (1978/1979); for mosses, that of Ireland et al. (1980); for liverworts, that of Stotler and Crandall-Stotler (1977); and for lichens, that of Hale and Culberson (1970). Unknown species were collected for later identification, and voucher specimens were collected for all bryophytes. These were deposited primarily at the Herbarium of the Great Lakes Forestry Centre (GLFC), Sault Ste. Marie; the National Herbarium, Museum of Natural Sciences, Ottawa; and the private herbarium of R.S.W. Bobbette.

Additional descriptions and measurements of the plots were collected; these included peat depth, depth to groundwater, pH of the groundwater, and peat pH (peat:water slurry, 1:1 volume) for peat samples collected from 0-20 cm and 20-40 cm.

Low-altitude Photos

Two overflights by fixed-wing aircraft were made to acquire 35-mm visible-spectrum color photographs from altitudes of between 100 and 500 m. Atmospheric haze and smoke from several burning peatlands in the area reduced the quality of these photographs.

Vegetation Types for LANDSAT Classification

Three systems of vegetation classification were assessed for their adaptability and interpretability with LANDSAT information. The OWC (Jeglum et al. 1974) is a system based on the physiognomy and dominance of the vegetation. It encompasses the whole of the wetland spectrum -- bogs, fens, swamps and marshes. The FEC (Jones et al. 1983) is a system of classification of the merchantable forests of the Northern Clay Section, which is located to the north of the current study area. It is based upon floristics only, and the wetlands that it encompasses are primarily conifer swamps and treed fens (Jeglum et al. 1974). Hence, the classification and the key for the FEC cannot be used, strictly speaking, for this study area, which is floristically richer and encompasses types of wetlands not included in the FEC data set. However, for the sake of comparison of the two areas, and to indicate where differences occur, the FEC system was applied. The four main FEC Operational Groups (OGs) that occur on organic soils in the Northern Clay Section are CHAMAEDAPHNE OG14, LEDUM OG11, ALNUS-HERB POOR OG12, and ALNUS-HERB RICH OG13.

A third classification, ELS, was also utilized to provide an independent evaluation of the ability of LANDSAT to interpret the other two classification systems. ELS was developed during recent multidisciplinary work done on biophysical land classification in eastern Canada (Anon. 1982a; footnote 2). This system was developed to provide a simple and flexible mapcoding system with a hierarchy designed specifically to classify air photos down to the level of detail required. The system is based on the physiognomy and dominance of the vegetation at the higher scales, as with the OWC, and of floristic types at lower scales, as with both the OWC and the FEC.

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[2] Bobbette, R.S.W. 1984. Assessment and ground-truthing of peatland classification using landsat imagery, Vol. 1 and 2. Rep. for Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont.

The field data set was initially classified into 27 ELS cover types that were developed from ELS vegetation-class definitions and from similarity of vegetational physiognomy and leading dominants (as determined from estimates of percent cover). In the ELS system, the highest level of vegetation is indicated by upper-case letters in the mapping code. The following main classes are used in this study:

"F" - **Forest-class Vegetation.** These are dense stands of trees, with 60% or more tree cover that provides dense shade on the stand floor. Usually there are very few shrubs, saplings, or light-demanding species.

"W" - **Woodland-class Vegetation.** These are open or broken stands with tree cover of 25 to 60%. Typically there is heavy shrub/sapling cover and/or an abundance of light-demanding herbs.

"P" - **Parkland-class Vegetation.** These stands are dominated by bryophytes, lichens, herbaceous plants or dwarf shrubs, accompanied by 10 to 25% cover of trees that are scattered or in small groups. There are typically very few tall shrub plants associated.

"S" - **Scrub-class Vegetation.** All sites with 30% or more cover of low and/or tall shrubs as the dominant stratum, with fewer than 10% trees, are assigned to this class.

Only wetland vegetation occurring on peat at least 40 cm deep was classified and used subsequently for LANDSAT analysis. This was possible at New Liskeard because the extensive clearing of upland sites resulted in LANDSAT signals that differed greatly from those of the mostly treed peatlands. The use of two seasons of LANDSAT imagery enhanced the separation of the undrained upland sites from the wetlands. Experience in other areas, in which uplands were covered with forests with the same dominant species as on peatlands, revealed that it is necessary to include uplands in both the vegetation classification and LANDSAT training exercises in order to approach a useful level of discrimination (see footnote 2, page 4).

Vegetation-training areas were manually extrapolated around the field sample sites in a very conservative manner; only the larger stands were delimited and coded with the full ELS format that includes drainage, terrain and water codes. Where required, additional training areas were classified by means of the low-altitude aerial photography, standard paired 1:15, 840-scale stereophotographs, and descriptions of vegetation (Anon. 1984).

During the selection of representative samples for the first LANDSAT training and analysis, seven cover types of very low coverage (fewer than 100 pixels) were eliminated, which reduced the 20 original cover types to 13 mapping types. These were increased to 14 mapping types during the second and final training and analysis. The final 14 mapping types, their component cover types and equivalents to the OWC and FEC systems are presented in Table 1.

Analysis of LANDSAT Data

Analysis of the LANDSAT imagery was carried out on the Aries II image analysis system of OCRS. The LANDSAT data employed consisted of MSS data, in digital format, that represented ground reflections in four wave-length bands: band 4 (0.5-0.6 μm), band 5 (0.6-0.7 μm), band 6 (0.7-0.8 μm), and band 7 (0.8-1.1 μm). The overlaid images from two seasons provided a total of eight values for each pixel (Table 2). The two data sets employed were LANDSAT 2 imagery from 30 August 1976 and LANDSAT 3 imagery from 21 May 1978. The two images were first registered to each other, then the resulting overlapping images were transformed to overlie a Universal Transverse Mercator (UTM) grid.

For the selection of representative samples (training areas) for each of the cover-type classes, a false-color composite image was displayed on the system's monitor. On the basis of this image, ground information and interpreted air photographs, the operator of the Aries II delineated each training area directly on the video display screen with the aid of a tablet-and-stylus apparatus (the "Hipad digitizer" by Bausch and Lomb).

After completing the training phase, the computer produced a signature for each mapping type that was composed of the means and standard deviations of signals from each of the four bands for each of the two seasons (Table 2). When training was completed, an autocorrelation (AU) comparison of the signatures of all mapping types was produced. This was a signature-by-signature comparison, with the value '0.0' indicating identical signatures and increasing numbers representing greater differences (Table 2). (When AU is 0.5, there is about 50% similarity; for AU = 1.0, about 30%; and for AU = 2.0, about 10%.)

After generation of the signatures, a maximum-likelihood classification algorithm was applied to the data. On the basis of signature statistics and pixel values, this algorithm calculated the probability of a pixel belonging to the populations represented by the signatures (classes) and assigned each pixel to the class most similar to it in statistical terms. Pixels that were not sufficiently similar to any of the classes remained unclassified.

The results of the classifications may be displayed on the computer's monitor, or may be reformatted and printed on paper or clear acetate with an Applicon ink-jet plotter. OCRS has developed software that enables the Applicon system to print a standard map format, with latitude and longitude reference points, UTM grid lines, annotation of features by characteristics and symbols, and a legend that includes area coverage and proportional representation of each theme. A color-composite map is also produced, generally before the classification is performed, from three of the LANDSAT image bands. This is particularly useful for a general overview, such as for navigation in a plane or helicopter.

Classification-confusion tables were also generated for each mapping-type signature file. This involved a pixel-by-pixel summary of the classification within all training areas. Both the autocorrelation exercise and the confusion tables compared all pairs of the 14 mapping types.

Table 1. Vegetation classification equivalents, Haileybury Clay Plain peatlands. The combination of ELS cover types into single mapping types is done to indicate transitions or mosaics of mapping types. Extrapolation that is 'not acceptable' is indicated by 'na' beside the map-type symbol.

LANDSAT map type	ELS cover type	OWC site type	FEC-OG
SCRUB TYPES			
Su	Speckled Alder Scrub	Speckled Alder Thicket Swamp	not included
Sb	Dwarf Birch Scrub	Glandular Birch Thicket Swamp	not included
Sd 'na'	Mixed Broadleaf Scrub	Willow/Alder Thicket Swamp	not included
Sl 'na'	Tamarack Scrub	Tamarack/Speckled Alder Conifer Swamp	OG13
Sv 'na'	Black Spruce-Alder-Herb Rich Scrub	Black Spruce/Speckled Alder Conifer Swamp	OG13
Sp 'na'	Shrubby Cinquefoil Scrub	Shrubby Cinquefoil Low Shrub Fen	not included
PARKLAND TYPES			
Pl	Tamarack Parkland	Tamarack/Sphagnum Treed Fen	OG13
Pxc 'na'	Px: Mixed Parkland	Willow/Alder Thicket Swamp	OG13
	Pc: Cedar Parkland	Willow/Alder Thicket Swamp	OG13
WOODLAND AND FOREST TYPES			
WcF 'na'	Wc: Cedar Woodland	White Cedar Conifer Swamp	OG13
	Fc: Cedar Forest	White Cedar Conifer Swamp	OG13

(cont'd)

Table 1. Vegetation classification equivalents, Haileybury Clay Plain peatlands. The combination of ELS cover types into single mapping types is done to indicate transitions or mosaics of mapping types. Extrapolation that is 'not acceptable' is indicated by 'na' beside the map-type symbol. (concl.)

LANDSAT map type	ELS cover type	OWC site type	FEC-OG
WOODLAND AND FOREST TYPES (concl.)			
WeF	We: Black Spruce - Tamarack Woodland	Black Spruce-Tamarack Conifer Swamp	OG11+OG12
	Fe: Black Spruce - Tamarack Forest	Black Spruce-Tamarack Conifer Swamp	OG11+OG13
WlF	Wl: Tamarack Woodland	Tamarack/Speckled Alder Conifer Swamp	OG12+OG13
	Fl: Tamarack Forest	Tamarack/Speckled Alder Conifer Swamp	OG12
WrF	Wr: Black Spruce - Ledum Woodland	Black Spruce/Labrador Tea Conifer Swamp	OG11
	Fr: Black Spruce - Ledum Forest	Black Spruce/Feathermoss Conifer Swamp	OG11
WsSe	Ws: Black Spruce - Leatherleaf Woodland	Black Spruce/Leatherleaf Treed Bog	OG14
	Se: Black Spruce - Tamarack Scrub	Black Spruce/Speckled Alder Conifer Swamp	OG12+OG13
Wx	Mixed Conifer Woodland	Black Spruce/Speckled Alder Conifer Swamp	OG13

RESULTS

First Analysis

The 13 most confused and the 16 most autocorrelated comparisons are presented in Table 3, which relates to a confusion limit of 11% and above and an autocorrelation limit of 0.9 and below. These types were summarized in tabular form on the basis of decreasing percent confusion and decreasing autocorrelation. Interpretation of the table suggested that some types could be reorganized or combined to improve the mathematical qualities of the LANDSAT signatures without being ecologically misleading. The trend of LANDSAT cover-type revision was to modify from types with ecological distinctness towards those with distinct signatures. This detailed study, and consideration of the training run, suggested that reorganization of the most confused mapping types could markedly enhance the ability of the computer to recognize them.

Table 2. Mean LANDSAT reflectance values for ELS mapping types.

Mapping types		Band 4	Band 5	Band 6	Band 7
BROADLEAF SCRUB					
Su	May 1978	31.6	34.9	60.5	61.6
	August 1976	32.5	28.6	100.4	108.4
Sd	May 1978	30.5	32.3	55.5	55.3
	August 1976	32.0	27.9	100.1	106.9
Sb	May 1978	31.7	34.1	73.7	77.9
	August 1976	34.3	32.4	93.9	96.8
Sp	May 1978	31.7	34.6	57.1	58.4
	August 1976	33.9	30.5	99.7	104.4
CONIFER SCRUB					
Sl	May 1978	30.9	32.9	66.7	69.4
	August 1976	32.7	29.2	94.4	98.3
PARKLANDS					
Pl	May 1978	31.6	33.3	71.5	74.5
	August 1976	33.8	30.4	86.3	86.6
Pxc	May 1978	32.3	35.3	69.3	72.4
	August 1976	34.1	31.4	93.4	95.1
CONIFER WOODLANDS AND FORESTS					
WsSe	May 1978	31.2	31.9	64.6	66.1
	August 1976	33.6	31.3	75.7	72.8
WrF	May 1978	28.4	25.8	58.4	59.1
	August 1976	31.9	27.1	71.2	68.1
WeF	May 1978	28.9	26.7	58.0	58.1
	August 1976	31.8	26.9	68.5	65.4
Wx	May 1978	29.2	27.1	60.7	60.3
	August 1976	32.2	27.9	71.1	68.4
WlF	May 1978	29.3	28.6	58.3	59.9
	August 1976	32.1	27.5	87.1	89.8

At this stage, 1:15,840-scale plastic transparencies of the classified training areas were generated. These were based on the original color composites of the LANDSAT data so that they could be registered to the mapped stereo aerial photographs. This registration demonstrated that the visual estimation technique, particularly at this detailed scale, produced highly variable results. Some of the training areas had not been correctly transferred to the computer display terminal. Because of this a second analysis was done in which the improved cover-type training areas (compare '1st' and '2nd' columns of 'Mapping Type', Table 3) were drafted directly onto the plastic LANDSAT transparencies and these transparencies were then used for the second and final computer training exercise.

Second Analysis

For the second analysis, training areas were transferred from the LANDSAT transparencies to the computer display terminal. There is a tendency towards circular argument during this critical stage of the LANDSAT training, as the operator outlines those pixels thought to represent the vegetation required. Even with interpreted aerial photos on hand, there is often some doubt about whether there is an exact correspondence between the air-photo unit desired and the computer representations thereof on the video monitor. The use of the LANDSAT transparencies with training areas plotted eliminated this tendency. In all cases it was possible to adjust the video-display image scale to match the transparency so that an exact transfer could be made even for areas in which pixel characteristics were otherwise confusing.

Objective transfer of training areas was very important in the context of the present study because of the low number of pixels (usually fewer than 200) used to develop the mapping-type signature files. Incorrect or hybrid pixels therefore had an inordinate influence on the mapping-type signatures.

After retraining, autocorrelation and classification-confusion tables were again generated, as well as LANDSAT means and covariances for each band that corresponded to mapping-type signatures.

In order to test the success of the retraining, the autocorrelation and percent confusion of the mapping types from the second analysis were listed beside equivalent types from the first analysis (Table 3). This summary indicates that the retraining reduced the worst confusion in almost all of the first-analysis classification types. In the best examples, confusion dropped from 13% (Pc-Sp) to 1% (Pxc-Sp), from 19% (Wc-Wex) to 4% (WcF-WeF), and from 14% (Slz-Wc) to 2% (Sl-WcF). The relative reduction of confusion by 75% or more can be considered a significant improvement.

There was not always a close coincidence between the confusion and autocorrelation analyses (Table 2). The decreases in confusion covered autocorrelation changes from 0.2 to 3.3. In one of the better improvements of confusion (reduced by a relative 86%) there was a reduction in autocorrelation of only 0.2. At this time, however, whether confusion or autocorrelation is more discriminative cannot be judged.

Table 3. Comparison of the first and second analyses by means of percent confusion and autocorrelation. Comparisons are among all possible combinations of pairs of the 14 mapping types on the basis of the pixels included within training areas for all types.

No. of pixels		Mapping type		Paired comparison with highest confusion (%)		Autocorrelation for same pair of types (0.0 = identical)	
1st	2nd	1st	2nd	1st	2nd	1st	2nd
I. The 13 most-confused pairs. Types are ordered according to decreasing percent confusion after the first analysis.							
303	119	FsW	WsF	32% Wex	22% WeF	0.2	0.4
147	134	Slz	Sl	23% Pl	10% Pl	0.6	1.4
468	413	Wex	WeF	19% FsW	14% WsF	0.2	1.4
195	124	Wc	WcF	19% Wex	04% WeF	0.9	1.5
204	177	Sb	Sb	19% Pl	04% Pl	0.7	1.1
227	167	Su	Su	17% Sp	13% Sp	1.4	1.0
147	134	Slz	Sl	14% Wc	02% WcF	1.1	1.3
196	109	FlW	WlF	13% Wex	07% WeF	1.0	1.6
136	177	Pc	Pxc	13% Sp	01% Sp	1.7	5.0
136	177	Pc	Pxc	12% Pl	12% Pl	1.8	1.2
111	177	Pz	Pxc	11% Pl	12% Pl	1.4	1.2
195	124	Wc	WcF	11% Flw	08% WlF	0.9	0.8
111	177	Pz	Pxc	11% Su	01% Su	1.8	3.4
II. The 16 most similar pairs. Types are ordered according to increasing values of autocorrelation (increasing differences) after the first analysis.							
468	413	Wex	WeF	19% FsW	14% WsF	0.2	0.4
303	119	FsW	WsF	32% Wex	22% WeF	0.2	0.4
195	124	Wc	WcF	11% FlW	08% WlF	0.6	0.8
196	109	FlW	WlF	13% Wc	06% WcF	0.6	0.8
98	98	Pl	Pl	06% Slz	05% Sl	0.6	1.4
147	134	Slz	Sl	23% Pl	10% Pl	0.6	1.4
204	135	Sb	Sb	08% Pz	05% Pxc	0.7	0.9
111	177	Pz	Pxc	05% Sb	06% Sb	0.7	0.9
136	177	Pc	Pxc	04% Sb	06% Sb	0.8	0.9
204	135	Sb	Sb	08% Pc	05% Pxc	0.8	0.9
468	413	Wex	WeF	07% Wc	02% WcF	0.9	1.5
195	124	Wc	WcF	19% Wex	04% WeF	0.9	1.5
195	124	Wc	WcF	09% FsW	13% WsF	0.9	1.2
303	119	FsW	WsF	06% Wc	02% WcF	0.9	1.2
204	135	Sb	Sb	09% Slz	13% Sl	0.9	0.8
147	134	Slz	Sl	05% Sb	04% Sb	0.9	0.8

Extrapolation of Landsat Vegetation Types

The final classification was extrapolated over the entire study area by the computer, and two sets of copies of classified transparent overlays were produced. One set of copies was kept for annotation and production of black-and-white prints while the other was cut up and individually registered to mapped air photos of the field study sites. Unclassified areas in the image were printed with the raw LANDSAT data to aid in registration of the overlay.

Extrapolation accuracy of areas more than four pixels in size was first tested for all mapping types by evaluating stands that had been actually sampled. Accuracy of extrapolation was further tested by comparing OGS field-survey data, low-altitude color photography, and the black and white stereo air photographs with the classified overlays. At least 20 extrapolated points were evaluated for each cover type. As well, the training areas themselves were analyzed for accuracy of classification; because the latter computer analysis reports 'accuracy' as a percentage, the manual-extrapolation accuracy test is reported in terms of 'accurate' (>75%), 'acceptable' (50-75%), and 'not acceptable' (<50%).

Ecological Land Survey Vegetation Mapping Types

The LANDSAT mapping types are listed in Table 4, along with the percentages of accuracy of classification of the training pixels, and the mapping types with which they were most confused. The percentages of accuracy of classification, and other types with which there was confusion, were generated from computer comparisons and classifications of each pixel in the training areas for each type, with the means for all of the types. The training areas were chosen to be larger than 4-6 pixels in order to avoid confusion with individual pixels that overlapped transitions or that otherwise produced spurious signals.

The types with the highest percentages of accuracy of all training pixels (79.9% and 78.4%, respectively) were Shrubby Cinquefoil (*Potentilla fruticosa* L.) Scrub (Sp), and Black Spruce-Leatherleaf (*Chamaedaphne calyculata* [L.] Moench) Woodland and Black Spruce-Tamarack Scrub (WsSe) (Table 4). Although the percentage of accuracy was high in Sp training areas, there was some confusion (9.6%) between Sp and Alder Scrub (Su) and Sp and upland broadleaf forests (mostly trembling aspen, *Populus tremuloides* Michx.). Apparently, the spectral characteristics of Shrubby Cinquefoil and Speckled Alder vegetation are similar. The use of two seasons of imagery emphasized the similarity of all deciduous types in comparison with the evergreens. There was little confusion between WsSe and other types.

Types with moderately high accuracy in their training areas (61.6 to 67.3%) were Tamarack Parkland (Pl), Mixed Broadleaf Scrub (Sd), and Mixed and White Cedar Parklands (Pxc) (Table 4). All of these types showed moderate levels of confusion with other wetland and upland types. Pxc corresponds to the thicket swamp of the OWC, and might be better included in an appropriate Scrub type.

The percentage accuracy of classification for the training areas was intermediate for seven mapping types (49.3 to 56.2%) (Table 4). These included four Woodland and Forest types (WeF, Ws, WlF and WrF), and three Scrub types (Sb, Su, and Sl). The percentages of confusion with other types are moderate to high.

Black Spruce/Alder/Herb-poor Scrub (Sv) and White Cedar Woodland and Forest (WcF) demonstrated very low percentages of accuracy, as well as high levels of confusion with other types (Table 4). These types were judged to be rather distinctive swamp types in the OWC system, yet in this excercise they showed 'not acceptable' extrapolation.

Inspection of Table 4 indicates that the four Woodland and Forest mapping types exhibit confusion among themselves, whereas the three Scrub mapping types are confused mostly with other Scrub types. Furthermore, the types with the same dominant species are the ones that tend to be confused among each other (cf. Tables 1 and 4).

Ontario Wetland Classification

The data from this study were incorporated quite readily into the OWC (Jeglum et al. 1974) with the exception of a few new site types that had to be added or grouped. In inspecting Table 1, one will note that each ELS mapping type represented a distinct OWC site type, with two exceptions. Mapping type WrF represents Black Spruce/Labrador Tea (*Ledum groenlandicum* Oeder) and Black Spruce/Feathermoss (mainly *Pleurozium schreberi* [BSG.] Mitt.) Conifer Swamp, and WsSe represents Black Spruce/Leatherleaf Treed Bog in combination with Black Spruce/Speckled Alder Conifer Swamp.

Low Shrub Fen: Two types are included here, Glandular Birch Low Shrub Fen (Sb) and Shrubby Cinquefoil Low Shrub Fen (Sp). These show some intergradation and confusion with Tamarack Treed Fens, in which Glandular Birch and/or Shrubby Cinquefoil are the dominant understory shrub types (Sl). This type of Treed Fen, in which a strong understory of intermediate-height shrubs exists, was not represented in the OWC. The abundance of this type here, in comparison with the Northern Clay Section, could be a result of the widespread drainage in the area and/or higher temperatures and evapotranspiration, both of which could result in drier conditions and more shrub development.

Treed Fen: The Tamarack/*Sphagnum* site type (Pl) was acceptably extrapolated and had a distinct training area. However, this type might be better related ecologically to Conifer Swamp because of its extremely woody peat.

Thicket Swamp: Thicket Swamp as a group was easily confused with broadleaf woodlands and forests on uplands. The Parkland mapping type (Pxc) should be reviewed and assigned to appropriate Thicket Swamp mapping types. The Thicket Swamps include two groups: Speckled Alder Thicket Swamp (Su) and Willow/Speckled Alder Thicket Swamp (Sd).

Table 4. LANDSAT mapping types arranged according to increasing confusion within the type. Only pixels within the training areas for each type were used and classified by comparison with the means of the signals for each of the 14 mapping types.

Mapping type (success)[a]	Accuracy of classification (%)	Types with which each mapping type was most often confused (% confusion)
Sp (na)	79.9	Su (9.6%)
WsSe (ac)	78.4	Wx (5.9%) WcF (3.8%)
Pl (a)	67.3	Sv (9.2%) Pxc (7.1%) Sl (6.1%)
Sd (na)	65.1	Su (7.1%) Sp (6.3%) WlF (5.9%)
Pxc (na)	61.6	Pl (12.4) Sl (6.2%) Sv (6.2%) Sb (5.6%)
WeF (ac)	56.2	Wx (20.8%) WrF (12.1%) WlF (4.6%)
Ws (ac)	54.0	WeF (22.1%) WrF (8.0%)
WlF (ac)	52.3	WeF (7.3%) WcF (6.4%) WsSe (5.5%)
Sb (ac)	51.9	Sl (14.1%) Sv (9.6%) Pxc (5.2%)
Su (a)	49.7	Sd (13.2%) Sp (12.6%) WlF (10.8%)
WrF (a)	49.6	WeF (21%) WxF (10.1%) Pl (5.9%)
Sl (na)	49.3	Sd (10.4%) Pl (10.4%) Sv (6.7%)
Sv (na)	30.8	Pl (23.9%) Pxc (15.4%) Sl (8.9%)
WcF (na)	26.7	WrF (11.%) WxF (10.6%) Sv (9.4%)

[a] Extrapolation success is coded in the following manner: (na) - not acceptable, (a) - acceptable, (ac) - accurate.

Conifer Swamp: This was accurately extrapolated as a broad group. The Tamarack/Speckled Alder Conifer Swamp is exclusively and accurately extrapolated as WlF, as is the Black Spruce/Labrador Tea Conifer Swamp site type as WrF. The Scrub form of Tamarack/Speckled Alder (+ Glandular Birch) Conifer Swamp (Sl) is 'not acceptably' extrapolated. Neither is the Scrub form of the Black Spruce/Speckled Alder Conifer Swamp (Sv), which gave a very confused training signature. Furthermore, Black Spruce-Tamarack Scrub (Se) could not be discriminated from Black Spruce/Leatherleaf Treed Bog (Ws). The White

Cedar Conifer Swamp (WcF) was correctly extrapolated at some sites, but not at others. Its mapping type should respond well to retraining. Two mixed Swamp types not originally defined in the OWC were trained and accurately extrapolated: Black Spruce-Tamarack Conifer Swamp (WeF), and Mixed Conifer Swamp (Wx).

Treed Bog: The Black Spruce/Leatherleaf site type (Ws) could not be separated from a mixed conifer form of Black Spruce/Speckled Alder Conifer Swamp (Se). However, the mixed mapping type (WsSe) was accurately extrapolated. Unfortunately, these two subtypes, which represent the ecologically distinct treed bog and conifer swamp, were not distinguished by this LANDSAT classification.

Forest Ecosystem Classification

One should not, strictly speaking, compare the types in the present study with those in the FEC, because the latter was developed on the basis of a sample from the Northern Clay Section (Jones et al. 1983), and the current study lies south of this area. However, the FEC is the most detailed classification for forest operational types close to the Haileybury Clay Plain, and it is made relevant by being part of the Boreal Forest continuum.

Four of the ELS mapping types do not have equivalents in the FEC (Table 1). This is because the FEC was limited to the merchantable conifer swamps. For the remaining mapping types, no Operational Group (OG) can be equated exactly with one mapping type. This may be explained in part because this area is south of the Northern Clay Section and is comparatively rich both floristically and in terms of forest productivity. The FEC system was applied with the use of a key that was based upon a limited set of indicator plants (Jones et al. 1983), and this key occasionally gave identifications that were obviously incorrect. What is most important, the OGs included a diverse mix of vegetational types, which are not at the same level of detail as the ELS or OWC classifications and often include much heterogeneity in terms of the canopy characteristics.

There are intrinsic difficulties in the LANDSAT discrimination of OG11, OG12 and OG13 where they are dominated by black spruce (with or without codominant or subdominant tamarack). In the New Liskeard area there seems to be mixing of OG14 with OG12 and OG13, but this may be a local phenomenon; OG14 may be identifiable from LANDSAT data in broader applications (Pala and Boissonneau 1983; footnote 2, page 4). Group-by-group comments follow.

OG11 LEDUM: The exclusive mapping type is WrF, which is acceptably extrapolated as small stands and pockets among mixed conifers. OG11 is combined with OG12 and OG13 in the WeF mapping type.

OG12 ALDER/HERB-POOR: The exclusive mapping type is Wx, which is accurately extrapolated as large and small stands restricted to wetlands. This type is mixed with OG11 and OG13 in WeF and with OG13 in WlF.

OG13 ALDER/HERB-RICH: The exclusive mapping types are WcF, Sv and Pl. Most of these are not reliably extrapolated, although WcF should respond to further training, and by extrapolation Pl can be improved despite its present acceptable level of extrapolation. Sv is very confused and may have to be abandoned. OG13 is combined with OG11 and OG12 in WeF, with OG12 in WlF and with OG14 in WsSe.

OG14 CHAMAEDAPHNE: This OG is mapped only in conjunction with OG13 in WsSe. The latter mapping type is acceptably extrapolated as stands and pockets, but its division into component OGs was not possible in this study.

DISCUSSION

Of the three vegetation classifications used in this study, the ELS and OWC classifications offered basically equivalent systems in terms of LANDSAT compatibility for peatland recognition. The ELS classification was used as the baseline in this study because it integrates wetlands into a broader landscape system. The FEC operational groups could be identified in several instances, but the mapping types derived from LANDSAT often included more than one OG. Apparently at the normal level of application of the FEC, there is not enough specificity of canopy characteristics to allow the clear distinction of the OGs from LANDSAT data.

The ELS system has been designed during several multidisciplinary environmental studies for a variety of user groups (e.g., footnotes 3 and 4; Anon. 1980, 1982b), and offers precise units of vegetation definition. It also allows foresters, wildlife biologists, landscape planners, and others to combine the more detailed types to produce units of the highest value to their work. The OWC has similar detail, but would require a complementary system to incorporate upland sites. Both the OWC and FEC systems require integration of non-vegetational data throughout their hierarchies. ELS progressively focuses on the integration of vegetation with other site factors, and only encourages the development of extremely detailed vegetation classifications where plant community features are not adequately indicated by the explicit inclusion of other site parameters in the combined ELS map code. This allows the ELS vegetation system to focus on the reflective cover, and so provides a malleable, potentially compatible system for LANDSAT training.

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[3] Bobbette, R.S.W. and Webber, J.M. 1979. Botanical inventory of the Copeland Forest Resources Management Area. Rep. for Ont. Min. Nat. Resour., Huronia District, Midhurst.

[4] Bobbette, R.S.W. 1983. Matchedash Bay Provincial Wildlife Area 1982 Botanical Inventory, Vol. 1 and 2. Rep. for Ont. Min. Nat. Resour., Huronia District, Midhurst.

As with normal air-photo interpretation, the use of more than one season of imagery aids not only the internal discrimination of peatland types, but also the separation of peatlands from similar non-peatland types. This results from the choice of seasons with contrasting reflectance features, e.g., late spring and early winter.

The four LANDSAT products investigated in this study were: 1. plastic transparent overlays of classified training areas and unclassified LANDSAT image background; 2. autocorrelation tables; 3. training-area classification-confusion tables; and 4. extrapolated peatland classification on plastic transparent overlays.

The plastic overlay was a fundamental tool for LANDSAT training in this study. The overlays allowed for the accurate transfer of training areas to the LANDSAT display monitor in the training phase. The overlays were also used with the stereo air photos to build semi-controlled mosaics, which aided in the extrapolation and testing of cover types and location of field samples. Without the use of overlays, the LANDSAT operator may fall into circular argument, or worse, produce spurious results because of the difficulty of precisely locating the vegetational features recognized from pre-typed air photos or maps on the 'blocky' LANDSAT color composite portrayed on the video display. The ability to register accurately at large scales greatly enhances research at smaller scales, where pixels are very small and blend together more.

Once training sites are objectively and accurately identified on the computer display terminal, the autocorrelation and training-area classification-confusion tables offer relatively quick and informative tests of the potential for the LANDSAT maximum-likelihood classifier to recognize desired types. One value of employing both tables is that although they show significant positive correlation, this is not absolute. For example, the retraining exercise demonstrated that increasing the similarity of two desired classification types could in fact result in decreased confusion between the training areas.

From this analysis, it is suggested that two types are no longer distinct when autocorrelation values are below 0.7 and when types have 20% or more of their training areas confused with one another. Types with these values should be reviewed for possible grouping together or redefinition.

It is important to view LANDSAT vegetation types in the context of the vegetation continua of which they form a part. Many types that are not well separated by LANDSAT are easily confused with closely related types. Further, this close relationship is in terms of both physiognomy and the specific dominant vegetation. The confused types may be considered subsets of a more accurately extrapolated, more generalized vegetation type.

The extrapolation accuracy of the classification will depend on the types and distribution of various vegetation continua occurring in the LANDSAT image. Thus, types with a great deal of integrity within the context of the training areas may in fact be so confused with spurious pixels and/or related upland types that they become 'not acceptable' for extrapolation (cf. Table 4). On the other hand, when wetland types are easily confused with closely related wetland types, it may be that their extrapolation is acceptable for most purposes.

The LANDSAT classifying algorithm is valuable because the user may adjust and add to desired classifications as additional data are obtained. Also, more detailed types may be grouped (for management, display or statistical purposes) either before or after overall classification of the image has occurred, depending on the character of the signature file.

Unless one is dealing with an extremely simplified landscape classification system, detailed ground-truthing and careful interpretation of project-appropriate aerial photography is essential, not only to classify vegetation properly in terms of existing categories, but also to discover any additional vegetation cover types not yet documented. This phase is critical to the selection of training sites used in gathering statistics for both supervised and unsupervised classification (cf. Quenet 1980). LANDSAT image analysis on the level of conventional 1:15,840-scale aerial photography cannot be used without a great deal of caution, and scales of 1:50,000 and smaller are certainly more applicable. However, new higher-resolution MSS imagery from satellites or aircraft may well offer better opportunities for interpretations at finer levels of detail.

CONCLUSIONS

1. The definition of peatlands by LANDSAT in northern Ontario is dependent mainly on the image features of the vegetational cover.

2. Vegetation classification, as employed for LANDSAT analysis, must be flexible enough to allow for grouping or splitting of classification types in direct response to the LANDSAT signature characteristics that are generated.

3. The Ecological Land Classification (ELS) vegetation system and the Ontario Wetland Classification (OWC) system were equally interpretable in terms of LANDSAT. However, the ELS system has an advantage in that it is specifically defined by coarse observation at higher hierarchical levels, with increasing detail and more specific site features used to aid definition of lower levels.

4. The definition of precise vegetation types, suitable for LANDSAT discrimination, requires accurate air-photo location of sample sites and the stands they represent, which must be registered to the LANDSAT image to within a tolerance of less than half a pixel.

5. The definition of general vegetation types suitable for LANDSAT discrimination may be accomplished from less precise locations of sample sites within large stands of at least 20-30 pixels in size, located to within a tolerance of 1-2 pixels on the LANDSAT image. In some cases expert air-photo analysis at a scale of 1:15,840 can be adequate for LANDSAT training, and field survey can be limited to careful description and census of the dominant reflective plant species.

6. The integration of LANDSAT images from different seasons is readily accomplished and highly advantageous for peatland vegetation analysis.

7. The maximum-likelihood algorithm is able to differentiate complex, intergrading peatland vegetation to a useful degree.

8. Each LANDSAT analysis can be viewed as a step, so that further research can be integrated with management and planning programs to identify those mapping types most compatible with the LANDSAT algorithm, and progressively improve their definition and extrapolation across the LANDSAT scene.

9. It is important that each LANDSAT research program provide precise air-photo-based documentation of sample-site locations and air-photo-registered LANDSAT overlays with training areas mapped and identified. This will allow other researchers to integrate future work positively, and to test former work.

10. The number of hybrids or otherwise misleading and unrepresentative individual pixels present in many LANDSAT scenes suggests that, at scales of 1:15,840, the minimum size for training areas should be no less than four pixels.

11. The most useful general application of LANDSAT classification and extrapolation is at scales of 1:50,000 and above, with nine pixels being the most practical minimum size of training area.

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