MOOSE HABITAT MAPPING IN CENTRAL NEWFOUNDLAND USING DIGITAL LANDSAT THEMATIC MAPPER DATA

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ABSTRACT: Earth Resources Satellite sensors are increasingly used to provide rapid and current mapping of large areas for wildlife habitat analysis. In 1986 the Newfoundland and Labrador Wildlife Division undertook an experimental project to assess the feasibility of Landsat Thematic Mapper data to classify and inventory moose habitat. A TM digitized format was selected because of its superior 30 m resolution, seven spectral bands, and convenient summary statistics. An area for which considerable moose population data were available, Moose Management Unit 24, was chosen as the project area. Cloud-free imagery was available for 26 August 1985. Analysis of the digital data was performed on a DIPIX ARIES-III image analysis system. Surface verification and accuracy assessment was provided by 1:40,000 colour infrared aerial photography acquired in 1983, 1:12,500 provincial forest inventory maps compiled in 1978, as well as ground and aerial surveys in 1986 and 1987. Nine vegetation cover types were identified using a supervised classification. Classes notable for moose included mature deciduous forest, immature coniferous forest, recent cutovers/slash, immature deciduous forest, mature mixed forest, and mature coniferous forest. Long term objectives are to use satellite imagery and radio-telemetry information to evaluate changes in moose habitat potential for the various moose management units across the province.

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Moose (*Alces alces*) is the most important big game species on the island of Newfoundland. Since 1973 the island moose population has been managed on a unit quota system, and hunting demand has required both knowledge of the current status of moose, and the capability of the available habitat in each Moose Management Unit (MMU). Earlier efforts to classify land for ungulate capability (Mercer and Kitchen 1968; Mercer *et a*l. 1972) used a combination of topography, soil, climate, and vegetative cover to determine the potential for moose and caribou. For moose specifically, the Newfoundland Forest Capability System, fashioned after Damman's (1964) forest type classification, was considered to adequately reflect habitat-type values, and associated moose densities derived from other studies. More recently, earth resources satellite sensors, eg. Landsat MSS and TM, have enabled rapid and current mapping of large areas for purposes of wildlife habitat analysis (Adams 1978, Thompson *et al.* 1980, Mayer 1984, Bright *et al.* 1986, Epp 1988). Among ungulates, habitat analysis using satellite imagery has been reported for elk (Bright 1981, Eby and Bright 1986), deer (Ormsby and Lunetta 1987), caribou (Dixon, Bracher and Meredith 1985), and moose (Laperriere *et al.* 1980, Bowles *et al.* 1984). These and other studies have been limited primarily to Landsat MSS data, and been generally successful, given the spatial and spectral resolution limitations of the sensor.

In 1986 the governments of Canada and Newfoundland and Labrador entered into a joint technology transfer program, designed to introduce provincial resource managers to remote sensing techniques. As part of this program, we undertook a demonstration project to classify and inventory moose habitat in an areas of central Newfoundland, using digital Landsat Thematic Mapper (TM) data. The objective of this study was to evaluate the use of satellite imagery as an operational mapping tool for providing up-to-date habitat information.

STUDY AREA

The area chosen for study was MMU 24 (Northwest Gander) in east-central Newfoundland (Fig. 1). Physiographically this unit lies within the Northeast Trough (Twenhofel and MacClintock 1940), and includes the area drained primarily by the Northwest and Southwest Gander Rivers. The topography is primarily a flat to gently rolling plain of low relief, sloping to the northeast.

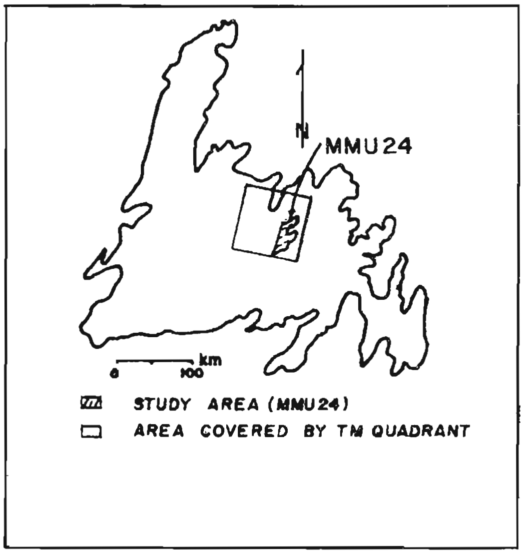

Fig. 1. Location of study area (MMU 24) and Landsat TM quadrant in central Newfoundland.

The forest forms part of the continuous boreal forest belt (Rowe 1959) with balsam fir (*Abies balsamea*) and black spruce (*Picea mariana*) as the dominant conifers and white birch (*Betula papyrifera*), aspen (*Populus tremuloides*) and mountain alder (*Alnus crispa*) as the most common deciduous species. Balsam fir is found mainly on undisturbed, nutrient-rich sites, and black spruce may grow with fir on the better soils, or may occur alone in stunted slow-growing stands on poorer sites, often in association with larch (*Larix laricina*) along bog edges. White birch is most commonly associated with fir, but occasionally occurs in pure stands. Aspen occurs mainly as species on burned-over and cut-over areas.

The forest in MMU 24 has had a long and varied history of logging. White pine (*Pinus strobus*) formed the mainstay of the lumber industry prior to the 1930's. More recently pulpwood logging in the 1960's and early 1970's has left a mosaic of variously aged cutovers throughout the unit. During the late 1970's outbreaks of spruce budworm resulted in extensive damage to balsam fir stands.

Over the past 20 years MMU 24 has served as a model for moose harvesting strategies and applied research in Newfoundland. This has been largely due to logging activity in the area, the associated hunter access, and relatively high moose densities brought on by regenerated stands of hardwoods and balsam fir. Aerial surveys of moose in this unit have been conducted each year since 1982, and a long- term radio-telemetry study is currently underway.

DATA AND EQUIPMENT

The Landsat series of satellites was inaugurated in 1972 to provide regular repetitive coverage of the earth's surface for resource mapping applications. Of the five Landsats launched to date, all have carried a Multispectral Scanner (MSS) sensor operating in four spectral bands with a spatial resolution of 80 m; the two most recent satellites, Landsats 4 and 5, have also been equipped with Thematic Mapper (TM) sensor, which acquires image data in seven spectral bands at a spatial resolution of 30 m (Table 1). We selected TM rather than MSS data for this study because of the desired mapping scale (1:50,000) and because we expected the additional spectral bands to provide a more detailed discrimination of vegetation cover types.

Landsat scenes are referenced geographically by path and row number; the project study area is covered by one quadrant (quarter scene) from Path 3/Row 26 (Fig. 1). A cloud-

Table 1. Spectral characteristics of Landsat TM bands.

Band number	Wavelength
1	0.45- 0.52 micrometre (blue)
2	0.52- 0.60 micrometre (green)
3	0.63- 0.69 micrometre (red)
4	0.76- 0.90 micrometre (near infrared)
5	1.55- 1.75 micrometre (shortwave infrared)
6*	10.50-11.50 micrometre (thermal infrared)
7	2.08- 2.35 micrometre (shortwave infrared)

*Band 6 data has a spatial resolution of 120 m; all other bands have a spatial resolution of 30 m.

free image of this area, acquired on 26 August, 1985 was ordered in the form of computer-compatible tapes (CCT's) with standard geometric and radiometric corrections applied.

We analysed the data using a DIPIX ARIES-III image analysis system located at NORDCO Limited in St. John's[1]. The ARIES consists of specialized image display hardware hosted on a VAX 750 together with a suite of software programs capable of a wide variety of image processing functions.

Surface verification ("ground truth") data were provided by 1:40,000 colour infrared aerial photography acquired in 1983, as well as 1:12,500 provincial forest inventory maps (reduced to 1:30,000) compiled in 1979. Field work consisted of ground inspection of various sites in August 1986, and an overflight of the area by helicopter in September 1987 to assess the accuracy of the final classification results.

METHODS

Preliminary Overview

Our initial step was to visually inspect the image data by assigning different TM bands to the red, green and blue guns of the colour monitor and applying appropriate contrast stretches. Three of the colour composites generated in this manner were found to be particularly useful:

a) Bands 3, 2, 1 (as red, green and blue respectively) produced a natural colour rendition, in which vegetation appeared as various shades of green. Although this combination provided familiar colour tones, it was poor in discriminating between vegetation types. It was however the best combination for discriminating forest access roads and bog areas and for identifying shallow water.

b) Bands 4, 3, 2 provided a similar spectral response to the colour infrared photography which was useful in comparing the two data sets. Mature conifers appeared dark purple, while mature deciduous stands were bright red. Immature stands of conifers and deciduous trees, while generally distinguishable, were both various shades of pink to red.

c) Bands 4, 5, 3 was overall the best combination for identifying the various vegetation categories. While reasonably similar to the colour infrared imagery, deciduous trees appeared orange and thus were more easily differentiated from the immature conifers (red). Areas affected by spruce budworm damage were also more clearly visible in this rendition, appearing green.

Preprocessing

Although the satellite data were corrected for geometric distortions introduced by the sensor and earth rotation, the resulting imagery was not referenced to a standard map projection; each line of the data ran southwest

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[1] The use of trade names is intended for information purposes only and does not constitute an endorsement on part of the governments of Newfoundland and Labrador or Canada.

to northeast, making direct comparison with maps and aerial photography rather difficult. Consequently we decided to correct the imagery to the Universal Transverse Mercator (UTM) projection, making it compatible with the 1:50,000 NTS map series.

We identified approximately 25 ground control points and calculated a transform function which was used to "resample" the image data. The output pixels corresponded to a ground area of 25 m by 25 m rather than the original size of 30 m by 30 m, in order to provide an integral number of pixels for each 1 km UTM grid cell.

The study area encompassed only about 20% of the original TM quadrant; however, this still represented quite a large data set, so we extracted four small subareas (approximately 10 km by 10 km each) in order to develop and test different classification procedures. We selected the subareas to correspond with the available aerial photography, to reflect the diversity of cover types within the study areas, and to be at least partially accessible by road.

Classification

Satellite data can be used to generate photographic products which can be analysed visually using conventional interpretation techniques. However, the use of digital data provides an alternative, in which the image analysis sytem assigns pixels in a scene to particular classes, based on their spectral reflectance characteristics. In an unsupervised classification, the classes are assigned on the basis of logical groupings or clusters of pixel values, without *apriori* knowledge of their environmental significance. It is then necessary to determine what cover type(s) each class represents.

Supervised classification, on the other hand, requires the analyst to establish in advance what cover types are present in the study area. Representative "training areas" are identified and a statistical tabulation of the pixel values is stored as a "signature" for each class. The system then compares each pixel in the scene to each of the signatures, and uses a "decision rule", eg. maximum likelihood, to determine to which class the pixel belongs.

We made an initial attempt at unsupervised classification in this project with disappointing results. While some classes were well defined in terms of surface cover, eg. mature conifers, water, other classes were either too large in that they encompassed too many cover types, or too small. For this reason we adopted the supervised classification approach.

In some cases it is possible to carry out supervised classification based solely on training sites identified through photo interpretation and the investigator's knowledge of the area. For this project however, the quality of the available photography was quite poor, and our familiarity with the study area was limited. Moreover, the forest inventory maps were out of date to the extent that there had been considerable regeneration in areas identified as clearcuts. Accordingly, we carried out field work in August 1986 to acquaint ourselves with current conditions in the area, and to identify suitable training areas.

We visited 32 sites in the field; their locations were annotated on the 1:40,000 aerial photography and notes and photographs were taken to document the vegetation cover at each. In this way we developed an initial stratification of the study area into habitat classes, and also improved our ability to interpret the photographs consistently.

We input training areas to the image analysis system using an interactive graphics tablet. Generally, we used between two and six separate "segments" to characterize each class. We calculated signatures for the various classes using TM bands 1-5 and 7. We excluded band 6, the thermal infrared band, because of its coarser spatial resolution (120 m) and because a visual inspection indicated that it contained little useful additional information.

With the signatures thus created we performed a maximum likelihood classification on the previously extracted subareas, using the default classification parameters. An inspection of the results showed a good correlation between computer-generated classes and known ground conditions. However, there remained an excessive number of unclassified pixels and some areas of apparent misclassification. We used a number of methods to refine the initial classification: we edited some of the training areas (either new segments added or old ones deleted); we created new training areas and signatures to represent previously unrecognised cover types; and we modified classification parameters to include a greater or lesser percentage of a particular signature.

In some cases the apparent accuracy of classification was dependent on the assignment of an appropriate label to a particular class. For example, we found that the class initially described as "slash-covered areas" also included other open areas with similar vegetative cover. Provided that a class consistently represented comparable habitat conditions, we considered this acceptable, and only changed the designation to more accurately describe the type(s) of cover present.

Following these editing procedures, we reran the classification for the four subareas and then used the modified signatures and classification parameters to classify the entire study area. .

Post-classification Filtering

Because the classification program operates on a pixel-by-pixel basis, the resultant map may have a "salt-and-pepper" appearance, in which isolated pixels belonging to different classes appear within otherwise uniform areas. In addition, a certain number of unclassified pixels generally remains, particularly in boundary areas where the pixel's spectral reflectance is a mixture of different cover types. Although this is the most accurate depiction of the classification results, it may be excessively "noisy" from an aesthetic point of view. Depending on the scale of the output plot, a certain amount of cartographic generalization may be desirable.

We used a technique of "post-classification filtering" to produce such a generalization. For this project, we decided to retain classified areas two pixels in size or larger, ie. eliminate single pixels, and to assign unclassified pixels to the class which had the largest number of adjacent pixels. Approximately 6% of the pixels in the study areas were single pixels whose class was reassigned following this procedure, while a further unclassified 5% was subsequently assigned to neighbouring classes.

Some question may exist as to whether such a cosmetic operation undermines the validity of the information presented. From a quantitative viewpoint, the "raw" classification results may in fact be preferable, but in terms of producing a map which can be visually interpreted, the "cleaned" version is superior. A single pixel occupies an unrecognisably small area at the 1:50,000 scale, and the concept of a minimum mapping element is well established. The assignment of unclassified pixels would present a problem if those pixels represented environmentally distinct areas. However, in our case an examination of the plots indicated that many of the unclassified pixels were single pixels, while most of the unclassified clusters were along the margins of water bodies or wet areas within bogs, and thus satisfactorily assigned to those classes.

Output

Digital images, by their very nature occupy rectangular areas composed of lines and columns of pixels. However, environmental information is usually required by resource managers on the basis of some type of administrative area, or natural physiographic unit such as a watershed. In order to delineate the study area (MMU 24) for statistical purposes, we used a "mask" to set all pixels outside the area to "unclassified". A final classification map at a scale of 1:50,000 was printed using a colour ink jet plotter. A statistical summary of all vegetation classes was tabulated which gave number of pixels, areal extent, and percentage of the total area occupied by each class.

RESULTS

Classification Output

Nine vegetation cover types were identified using a maximum likelihood classification process for the entire study area. These cover types included:

1. Mature coniferous forest (MC)
2. Immature coniferous forest (IC)
3. Mature deciduous forest (MD)
4. Immature deciduous forest (ID)
5. Mature mixed forest (MM)
6. Treed bogs/sparse coniferous forest (TB)
7. Open bogs (OB)
8. Budworm kill/deadfall (BD)
9. Cutovers/slash (CS)

In addition water (W), roads/bare ground (RG), and sand/gravel (SG) were also identified as separate classes.

As a means to assess the impact of post-classification filtering, we produced summary statistics comparing the "raw" and "cleaned" versions of the various cover types in our study area (Table 2). It should be noted that the percentage figures have been normalized to the area occupied MMU 24; in other words, portions of the scene outside of the study area, and subsequently flagged as "unclassified" were not included. Although there were minor adjustments up or down for each cover type between the two versions, the ranking remained the same, with mature coniferous forest, immature coniferous forest, open bogs, treed bogs/sparse coniferous forest, and budworm kill/deadfall comprising the top five cover types in descending order.

Accuracy assessment

As a means to assess the accuracy with which our classification depicted actual ground cover conditions, we conducted an aerial overflight on 5 September 1987 of part of our study area, examining 111 cells of 4x4 pixels square from a Bell 206 helicopter

Table 2. Summary statistics on classified cover types for Moose Management Unit 24, 26 August 1985.

Classification	No. pixels		area (km^2)		Percent of total area	
	Raw	Cleaned	Raw	Cleaned	Raw	Cleaned
Mature coniferous	318461	344811	199.04	215.51	22.75	24.63
Immature coniferous	181639	178953	113.52	111.85	12.97	12.78
Mature deciduous	61335	63247	38.33	39.53	4.38	4.52
Immature deciduous	106368	110410	66.48	69.01	7.60	7.89
Mature mixed	76973	75234	48.11	47.02	5.50	5.37
Treed bog/sparse coniferous	124810	122006	78.01	76.25	8.91	8.71
Open bog	144984	159516	90.62	99.70	10.36	11.39
Budworm kill/deadfall	107933	115336	67.46	72.09	7.71	8.24
Recent cutovers/slash	78511	85542	49.07	53.46	5.61	6.11
Water	87923	104054	54.95	65.03	6.28	7.43
Roads/bare ground	36882	38130	23.05	23.83	2.63	2.72
Sand/gravel bars	2370	2716	1.48	1.70	0.17	0.19
Unclassified	71778	-	44.86	-	5.13	-
Totals	1399963	1399963	874.98	874.98	100.0	100.0

hovering at 30-50 m above the ground cover. We initially selected 182 cells from 364 randomly distributed points in the area of interest, but due to aircraft time constraints decided to concentrate on cover types whose identification on the infrared photographs was questionable.

This task was made more difficult by the fact that many of the cells contained pixels of more than a single cover type. In addition, although we accurately transferred cells from the cover type maps to the infrared colour photographs, a certain amount of error could be ascribed to problems of locating oneself in the helicopter above the cell in question, and thus improperly describing the vegetation below the aircraft.

Given the above constraints, a comparison between cover types observed and described from the helicopter and those identified by the computer classification (Table 3), showed that overall accuracy was highest for cutovers/slash, budworm kill/deadfall, and mature coniferous forest. Lowest accuracy occurred with mature mixed forest and treed bogs/sparse coniferous forest.

Recognizing the limitations of our accuracy assessment, we nevertheless felt that this exercise could be used to focus attention on some problem areas in our classification, as well as indicate cover types which could consistently be identified correctly. Cover types which were a result of recent disturbance, ie. budworm kill/deadfall, cutovers/slash were easily distinguished, as were areas of rather uniform cover, such as mature coniferous forest and open bogs. Regenerating vegetation could generally be distinguished, but an "immature mixed" class might have been desirable.

Greatest errors were found with the mature mixed forest and treed bogs/sparse coniferous forest. Both of these may be considered as transitional cover types; in the former case mixed forest consists of both coniferous and deciduous elements, and these classes were most commonly confused with mature mixed forest. Similarly, treed bogs/sparse coniferous forest was most often confused with mature, and immature and mature coniferous forest.

In practical terms, these particular mis-

Table 3. Comparison of cover types identified from helicopter observation versus those identified by computer classification, MMU 24, Newfoundland.

Computer Classification	Aerial survey												
	MC	IC	MD	ID	MM	TB	OB	BD	CS	W	RG	UC	Total
Mature coniferous forest (MC)	10				3	5							18
Immature coniferous forest (IC)		10	1		1	4							16
Mature deciduous forest (MD)			6	1	3								10
Immature deciduous forest (ID)		3		3	1	1			1				9
Mature mixed forest (MM)		1	1		5	2							9
Treed bogs/sparse coniferous forest (TB)				7	2						9		
Open bogs (OB)		1					6						7
Budworm kill/deadfall (BD)	2		1					8					11
Cutovers/slash (CS)			3					1	13				17
Water (W)										1			1
Roads/bare ground (RG)											1		1
Unclassified (UC)				1						2			3
Total	12	15	12	5	13	19	8	9	14	3	1		111

classifications may not be critical in the overall depiction of habitat types. However, more extensive fieldwork would have been desirable to assign some quantitative value to the proportion of coniferous and deciduous trees which resulted in a mature mixed forest classification, and to determine the threshold level of crown closure which defined treed bogs/sparse coniferous forest. It would then be possible to assess how reliably or consistently the classification performed.

There was a discrepancy between some of the cells identified as mature deciduous forest from the aerial survey and classified as cutovers/slash by the computer. We were unable to come with any plausible explanation for this, since spectrally these two classes were quite distinct. The apparently low classification success for water is also misleading; in other studies water is almost always the most accurately identified class, usually in the range of 95-100%. As can be seen in Table 3, only three cells classified as water were checked, and two of these were apparently "unclassified". We believe that this was the result of our concentrating aerial checks on "problem" areas. Overall, our classification of water was near-perfect, and the unclassified cells were almost certainly areas of shallow water, either small roads, or along the margins of lakes or rivers.

Comparison with Field Data

As stated in the methods, we conducted field surveys of the study area in August 1986, to familiarize ourselves with ground conditions which could not be adequately determined from the aerial photos and forest inventory maps, as well as to identify suitable training areas for the supervised classification. A total of 32 sites was examined, and each of these was described in terms of dominant tree cover, spacing, height, and other ground cover conditions which might affect spectral reflectance. Although we used a number of these sites as training areas for our classification, many of them contained a diversity of cover types, which was borne out in the classification results.

While not a quantitative measurement of classification accuracy, we believe that comparing the field descriptions of these sites, and their eventual classification from the TM data, provides an appreciation both of the diversity of vegetation present in the study area, and the ability of the classification to depict it (Table 4). It should again be noted that the classification labels given in Table 4 are based on the "raw" results, and in the "cleaned" version, infrequently occurring classes were often filtered out. Our subjective evaluation of the final classification was that it provided a very good representation of the vegetation cover present in the study area, and compared favourably to the level of information that could be interpreted from conventional 1:40,000 aerial photography.

DISCUSSION

Implementation

Assuming that satellite-derived habitat information is a potentially useful tool for wildlife management, can it be applied practically in an operational setting? To answer this question, we examined the costs involved and the available options in carrying out a project of this type. Alternative strategies for obtaining habitat information were also considered.

The first cost is that of the satellite data. In this study we used digital seven-band Thematic Mapper data from one Landsat quadrant. At current prices (1987-88) this data cost $1580 Cdn. Although MMU 24 is one of the smaller units in the province, it appears that on average, two MMU's can be mapped from each quadrant. The cost of data per unit area could be considerably reduced by ordering data in full scenes, ie. four quadrants; the corresponding cost for seven-band digital data is currently $3480. Further savings could be realized if only three of the seven bands were ordered. In this case, the costs for

Table 4. Ground description of sites examined on 26-29 August 1986, and ultimate Landsat TM classification(s).

Site No.	Ground Description	Landsat TM Classification
1	Mature conifers; mainly black spruce with white pine, 8-15 m	Mature coniferous forest
2	Open coniferous regeneration; mainly black spruce and balsam fir, 3-5 m, interspersed with heaths and lichens	Immature coniferous forest Open bogs Treed bog/sparse coniferous Roads/bare ground
3	Alder and bog	Immature deciduous forest Open bogs Cutovers/slash
4	Mixed forest; black spruce and birch/aspen, 20-25 m, with deciduous understory	Mature deciduous forest Immature coniferous forest Mature mixed forest
5	Cutover/slash; open regeneration of spruce, pine, birch and heaths	Cutovers/slash*
6	Open regeneration; spruce, 2-3 m, interspersed with slash, scattered remnant poplars	Cutovers/slash
7	Mixed mature forest; fir, birch, aspen, deciduous understory	Mature mixed forest Mature deciduous forest Immature deciduous forest Mature coniferous forest Open bogs
8	Mature conifers, 10-15 m	Mature coniferous forest*
9	Medium dense coniferous regeneration; spruce, fir, 2-3 m, backed by alder, then mixed forest	Immature coniferous forest Mature mixed forest Mature deciduous forest
10	Medium dense coniferous regeneration; spruce, fir, 2-3 m, interspersed with heaths, slash and sphagnum	Immature coniferous forest* Open bogs
11	Deciduous regeneration; alder, willow, birch, interspersed with spruce and fir, 3-5 m.	Mature deciduous forest Immature coniferous forest Immature deciduous forest Mature mixed forest
12	Medium dense coniferous regeneration; spruce, fir 2-4 m	Immature coniferous forest
13	Deciduous regeneration; poplar, birch, cherry, 5-7 m	Mature deciduous forest Mature mixed forest Immature coniferous forest
14	Mature conifers; spruce 7-15 m, larch and fir on periphery	Mature coniferous forest Treed bog/sparse coniferous forest

Cont'd.

Site No.	Ground Description	Landsat TM Classification
15	Mature conifers; 15-20 m	Mature coniferous forest*
16	Open coniferous regeneration; spruce, pine, scattered birch, 3-10 m, heath-lichen understory	Immature coniferous forest Mature mixed forest Mature coniferous forest
17	Open budworm-killed fir; 12-16 m, raspberry understory	Budworm kill/deadfall*
18	Mature deciduous forest; birch, cherry, scattered fir, 10-15 m	Mature deciduous forest* Mature mixed forest
19a	Mixed mature forest; birch, cherry, fir, 7-15 m, scattered budworm-killed fir, birch-fir understory	Mature mixed forest Budworm kill/deadfall Mature coniferous forest
19b	Mixed mature forest; birch, cherry, fir, 10-15 m, birch-fir understory	Mature deciduous forest Mature mixed forest Immature deciduous forest
20	Open coniferous regeneration; spruce, pine, scattered birch, aspen, 7-13 m, interspersed with heaths, lichens, slash	Mature mixed forest Immature coniferous forest Mature coniferous forest
21	Open coniferous regeneration; spruce 3-7 m, interspersed with heaths and lichens	Immature coniferous forest Mature coniferous forest
22	Road, bare ground, scattered larch, alder, 1-2 m	Roads/bare ground
23	Open coniferous regeneration; fir, 5-7 m	Immature coniferous forest
24	Bog; scattered spruce, 1-2 m, heaths	Open bogs*
25	Medium dense coniferous regeneration; spruce, fir, 2-5 m, scattered alder	Immature coniferous forest Immature deciduous forest
26	Bog; scattered larch, spurce, alder, 1-2 m, reeds-heath-spaghnum	Open bogs*
27	Open budworm-killed fir; scattered spruce, alder, 3-4 m, birch-raspberry understory	Cutovers/slash
28	Alder, budworm-killed fir, scattered spruce, fir, 3-8 m	Immature deciduous forest Cutovers/slash Open bogs Immature coniferous forest
29	Medium dense coniferous regeneration; spruce, fir, 3-5 m, scattered larch, alder, 2-3 m	Immature coniferous forest Immature deciduous Mature mixed forest

Cont'd.

Site No.	Ground Description	Landsat TM Classification
30	Open budworm-killed fir; 3-4 m, scattered spruce, 10-15m, alder	Immature coniferous forest Cutovers/slash forest Immature deciduous forest Open bogs Mature mixed forest
31	Mature conifers; spruce 10-15 m, scattered fir, 2-4 m, heath understory	Mature coniferous forest Mature mixed forest

* Sites used as training area for classification signature

quadrant and full scene coverages would be $740 and $1480 respectively. While we did not test the use of three-band data for classification in this study, we expect that it should be possible to achieve comparable results given the similarities in spectral response within the three visible bands (1, 2, and 3) and the two shortwave infrared bands (5 and 7).

The time (and hence the cost) required for the digital image analysis is more difficult to quantify for two main reasons. Since this was a pilot project, we spent considerable time gaining familiarity with the system and exploring different analysis options. In an operational setting, certain economies of scale could be realized by processing larger geographic areas. For the purposes of this discussion therefore, certain assumptions had to be made.

We assumed that analysis would be undertaken for a complete Landsat quadrant, using six bands of data, and that the imagery would be registered to the UTM projection. If the use of three rather than six bands was justified, the amount of processing could be reduced significantly. We also assumed that 12 cover classes (as used in this study) would be adequate to characterize a given area. Given these assumptions, and based on our experience, we estimate that approximately 20 to 30 hr of interactive system time (with an operator), and 70 to 90 hr of "batch" processing time (without an operator) would be required from data input to production of 1:50,000 colour plots and statistical summaries.

Based on commercial rates now being charged in Newfoundland, this translates to a cost of between $7000 and $9000; different rates may apply in other areas. If there is sufficient demand for this type of analysis, it may be worthwhile to acquire an an-house image analysis system. Microcomputer-based image analysis systems are becoming increasingly affordable, and can support a variety of peripheral devices, such as 9-track tape drives and colour plotters. The computer would also be useful for other applications; for example, running a geographic information system (GIS), which could combine classification results with other data, eg. elevation, to model habitat capability.

The above costs reflect only the requirements for image analysis and do not include time spent to acquire surface verification data. This would presumably involve procuring new or existing aerial photography and forest inventory maps covering at least 5% of the total study area. Field visits should also be undertaken if the project personnel are not completely familiar with the area. We stress that knowledge of local conditions can greatly enhance the success of any image analysis exercise. For this reason we recommend that the analysis be undertaken by at least one person with a knowledge of the area, and/or habitat requirements, and another person familiar with digital image analysis.

If the cost of digital analysis cannot be justified, satellite data may still be usable in photographic format. A 23 cm by 23 cm colour transparency (1:500,000) currently costs $300 for one Landsat TM quadrant. Using a suitable enlargement system, this imagery is quite acceptable for mapping at a scale of 1:50,000. The main operating cost then is the cost of photo-interpretation. However, if the habitat information is to be entered into a GIS or some other type of data base, the interpreted information will still have to be digitized.

We point out that satellite imagery compares very favourably with conventional aerial photography for applications similar to this study. In order to cover a corresponding area (93 km by 88 km) at a scale of 1:40,000, approximately 360 photographs are required for stereo coverage, or 180 for non-stereo coverage. Although the aerial photographs contain much more spatial information, eg. with enlargement, individual trees can be detected, we do not believe that such detail is needed for this type of habitat mapping. Furthermore, satellite imagery is likely to be much more recent for any given area than existing aerial photography, and the cost to acquire new photography would be prohibitively expensive for most wildlife agencies.

An alternative to mapping habitat directly, either from satellite data or aerial photography, would be to rely on information compiled by other agencies; in particular forest inventory data compiled by provincial or state forestry departments. One of the difficulties with this approach is that the forestry information is, in many cases, too detailed to be easily assimilated into specific habitat types, while in non-productive areas, the information may not be detailed enough. However, since inventories are now being put into digital geographic information format in many areas, the potential exists to manipulate that data to derive habitat classifications similar to that obtained from satellite analysis. Specialized output of this type also need not be limited to the standard scales currently used for forestry applications.

Unfortunately in Newfoundland, and we suspect in many other jurisdictions, there are no mechanisms currently in place which allow wildlife managers (and others) to access this data in digital form and derive their own information products. Efforts should be made to foster this kind of interagency cooperation, as it can reduce the need for each agency to collect land cover data independently. Although existing forest inventories may be out-of-date in some areas, the use of satellite data to provide more frequent updates should help to alleviate this problem.

Application

The identification, location and extent of habitat cover types for moose is the first step for more precise management of the species in Newfoundland. We currently lack information on habitat potential for moose; population surveys are conducted infrequently, so little knowledge exists on the current status of most MMU's. Population estimates have been derived for MMU 24 in recent years. The area also contains a sample of radio-collared moose, whose distribution, movements, productivity and mortality have been studied since 1983.

We believe the moose population in MMU 24 is at or near the habitat potential of the area, and we intend to use the distribution of radio-collared sample to determine what each of the cover types identified in this study contributes to the requirement of moose in this saturated population. We need similar habitat data for other MMU's where we know less about moose numbers, and where we suspect the population may similarly be approaching the potential of the habitat.

The areal extent of the various cover types within other MMU's can possibly be used to predict levels for moose populations, using MMU 24 information as optimum density figures for each cover type. By correlating hunter trend indices for the various MMU's to the available classes and potential for each, we may be able to establish appropriate harvesting schedules to move moose populations toward the desired target for each MMU.

CONCLUSIONS

The overall objective of this study was to assess satellite imagery as an operationally rapid and current technique to identify the location, extent, and spatial configuration of vegetation cover types relevant to moose in Newfoundland. We selected TM data in digital format for this study because of sensor's superior resolution and multiple spectral bands, and our wish to have a computerized data output.

We began the study early in 1986, using an image obtained for August 1985. As Landsat provides repetitive coverage every 16 days, it is quite reasonable to expect a usable image for each season every year for most areas. We thus believe the technique has the potential to be extremely current, especially in relation to conventional mapping/photo products now in use by our agency.

We believe the classification of nine vegetation cover types for MMU 24 to be a satisfactory habitat inventory for moose. Some questions remain, such as how to distinguish balsam fir from black spruce in coniferous or mixed stands. In MMU 24 we found few live stands of mature balsam fir; virtually all mature conifers were black spruce, but regenerating stands often contained both species. We also need to better define the proportion of deciduous versus coniferous trees in mixed stands, and to distinguish the coniferous components of treed bogs/sparse coniferous forests.

The cost of digital imagery and the associated image analysis expenses may be prohibitive for some agencies. In such cases, the use of satellite-based photographic products should be considered as an alternative to either existing or specially acquired aerial photography. Although it was not our intention to compare the data content of aerial photography versus satellite imagery, we believe the 30 m by 30 m pixel resolved by the Landsat TM is an appropriate mapping element for moose habitat inventory, and may also be useful in applications to other wildlife species.

In our judgement, the advantages of digital analysis outweigh the initial costs. Attempting to hand-calculate areas of the various cover types would be an extremely time-consuming exercise. Computerized digital output allows for accurate and statistical summaries of the information for any given area, and mapping scales can be integrated with products presently used by wildlife, and other resource agencies. The integration of digital land cover information, whether from satellite data analysis or from other sources, with other types of information allows development of habitat capability models which will ideally lead to more effective management of wildlife resources.

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