Woodland Caribou (*Rangifer tarandus caribou*) Habitat Classification in Northeastern Alberta Using Remote Sensing

Fish & Wildlife Division

WILDLIFE CONSERVATION AND BIODIVERSITY SECTION

Species at Risk Report No. 33

Alberta
SUSTAINABLE RESOURCE DEVELOPMENT

Woodland Caribou (Rangifer tarandus caribou) Habitat Classification in Northeastern Alberta Using Remote Sensing

G. Arturo Sanchez-Azofeifa
and
Robert Bechtel

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EXECUTIVE SUMMARY

Woodland caribou habitat mapping in northern Alberta, Canada is incomplete and imprecise, as habitat relationships are not fully understood, and land cover mapping is neither consistent nor complete. The spectral reflectance information that can be obtained through remote sensing observations makes possible the identification of important woodland caribou habitat over large areas. With the use of Global Positioning System collars fitted on the animals, correlations between satellite observations and Global Positioning System caribou locations can now be explored. This final report examines the results of a methodology that integrates Landsat 5 Thematic Mapper imagery in the Northeast Boreal region and a dataset containing nearly 100,000 caribou locations acquired from Global Positioning System radio-collars for thirty-six individuals in order to identify the areas of potential use by Caribou. The procedure was repeated using a separate dataset containing approximately 5000 Very High Frequency radio-collars to validate the technique. The intent was to determine if reflectance characteristics could be related to caribou preference or avoidance. If so, it is possible to predict caribou habitat selection in areas where there are no collared animals. Reflectance classes preferred by caribou were grouped into three categories. These were preferred, regardless of season (73.1% of all caribou locations). The first class appears to be dominated by black spruce *(Picea mariana)*, which occupies 31.6% of the entire study area and accounts for 49.7% of the caribou locations. The second class is characterized by shrubby fen. It occupies 13.0% of the entire scene and accounts for 17.2% of the caribou locations. The final class is also peatland-related, but it has not yet been characterized by physiography or vegetation type. It makes up only 3.7% of the study area, but accounts for 6.2% of the caribou use. The remaining 26.9% of the telemetry locations fall within various cover types that were not preferred by caribou. This study demonstrates how remote sensing, Geographic Information Systems techniques, and ecological information can produce the kinds of information necessary for sustainable land management.

1.0 INTRODUCTION

Woodland caribou (*Rangifer tarandus caribou*) in Alberta, Canada is considered 'threatened' by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2000), as well as is also considered endangered specie under the Alberta Wildlife Act (AEP 1994a). In addition, woodland caribou is part of Alberta's 'Blue List' of species, a list that catalogues those species that may be at risk and have undergone non-cyclical declines in population or habitat, or reductions in distribution (Alberta Wildlife Management Division 1996).

Mapping woodland caribou habitat is extremely difficult in northern boreal forests because the harshness of the environment and because of the difficulty in observing caribou populations (Stuart-Smith et al. 1997; Bradshaw et al. 1995; Dzus 2001). The species tends to be cryptic by nature and exists in low-density populations throughout the Alberta Landscape (Dzus 2001). Previous caribou habitat mapping in Alberta has been generated from existing peatland inventory maps (Schneider et al. 2000; Bradshaw et al. 1995) as peatland complexes have been identified as being extremely important to woodland caribou (Fuller and Keith 1981; Bradshaw et al. 1995). While effective, the use of peatland maps for habitat identification is still limited to information directly related to peatland classification. For example, in Schneider et al. (2000) only the highest level of classification from the peatland map was used, resulting in categories of Bog, Fen, Marsh, Swamp, Non-wetland, and Non-peat. In Bradshaw et al. (1995), seven peatland habitat types were used. Stuart-Smith et al. (1997) observed the relationship between home ranges and fen complexes, but used only two categories of land cover, fens and upland, to represent ground cover. While all of these approaches accurately relate caribou use to peatland, they are limited by the categorization of a map that was not intended for wildlife mapping. Thus, upland areas and other non-peat areas are broadly categorized.

Based on the need for a more detailed caribou habitat map, this final report describes a method of combining remote sensing and GIS techniques to delineate woodland caribou habitat selection in Alberta. The goal of this methodology is to evaluate the robustness of remote sensing as a tool to identify woodland caribou in combination with telemetry data. The specific objectives of this report are:

- **Objective No. 1:** Using the ground cover classification developed by the EOS-Lab for the Wabasca study area in 1999-2000, extend this classification to adjacent images that were acquired on the same day.

- **Objective No. 2:** With the use of Alberta Vegetation Inventory (AVI), validate the ground cover classification described above. This will result in a "finished" caribou habitat classification map for the Wabasca study area. AVI data sets are to be provided by Alberta-Pacific Forest Industries.

- **Objective No. 3:** Compare (overlay within a G.I.S. environment) VHF caribou collar locations from the Wabasca study area with the finished caribou habitat classification map developed in Objective 2, above, and identify correlations.

- **Objective No. 4:** Investigate issues of scale and landscape structure for the Wabasca study area by examining the effect of altering the minimum mapping unit.

- **Objective No. 5:** Based on results from VHF collar analysis for the Wabasca study area (Objective 3), identify correlations between VHF collar locations and Landsat imagery for the Alberta Portion of the Cold Lake Air Weapons Range (CLAWR). Determine the effectiveness of these data sources for predicting preferred caribou habitat within this area.

- **Objective No. 6:** Using Landsat images already available to the EOS-Lab, and applying the interpretations developed in the preceding steps, extrapolate the results form these two local caribou habitat study areas (Wabasca and CLAWR) to the remainder of that portion of the northeast Alberta describe in Figure 1 of the contract.

2.0 DATA AND METHODS

2.1 Data

Caribou habitat selection was determined through the use of GPS location information from thirty-six different animals between a period from February 22, 1998 to August 22, 1999. Telemetry data was acquired from the Boreal Caribou Research Program and has been used in a number of previous studies (Anderson 1999; Dyer 1999). The GPS locations were measured using a Lotek Engineering GPS animal location system in combination with a Trimble base station located at a nearby millsite. The original database included information on 103,712 individual caribou locations.

The caribou locations were initially divided into four seasons (winter, spring, summer, and fall) to determine whether or not caribou alter their habitat choices at different times of the year. However, there was no significant variation in percent of occurrence from season to season, so the decision was made to analyze the dataset as a whole with no division of seasons.

Locations without differentially corrected fixes were removed from the dataset. This decreased the overall number of locations from 103,712 to 98,803, a loss of 4.7% of the original dataset. The filtered database was divided into two samples so that one half of the points could be used in the caribou habitat analysis and the other half could be used to test the validity of the analysis. Eighteen animals were used in sample A (analysis) and another eighteen were used for sample B (validation). The occurrence of caribou locations within each spectral class was obtained as an average of the eighteen animals within each sample. This ensured that an animal that recorded more location data (i.e. was collared throughout the entire study period) did not get over-represented compared to an animal that recorded less location data (i.e. the animal was killed during the study period, GPS unit malfunctioned, etc.). The caribou locations from sample B were then compared to the classification created from sample A. Repeating the identical procedure, the correlation between spectral reflectance and sample B locations were obtained and compared to sample A.

Spatial auto-correlation was addressed by a simple procedure based of the 25m by 25m resampled pixel size. Because frequent successive location data can be positively correlated (Swihart and Slade 1985), locations that occupied the same spectral class from one location to the next were removed from the dataset. Location data was only used if the individual caribou moved from one spectral class to a different spectral class. In other words, if the pixel value of one location was the same as a second location, then the second location was removed from the dataset. This reduced the likelihood that a caribou that is bedding, resting, injured, or for any other reason not changing its location, is not over-estimated for its occurrence within a particular spectral class.

While the validation (sample B) verifies the effectiveness of the procedure, another validation, using location data from completely different caribou, can further verify the effectiveness of the caribou habitat spectral preference. A third caribou dataset was collected using VHF telemetry from the Wabasca area. The animals used were never equipped with a GPS unit, thus ensuring that different individuals were being tracked. The dataset was collected over the same time period as the GPS dataset. The initial dataset was 7,326 locations, with 5,201 locations falling within the minimum convex polygon that was created from the GPS dataset (Figure 1). Spatial auto-correlation was not applied to the VHF dataset, as it was a significantly smaller dataset with a much slower rate of location acquisition. As a result, independence of successive observations is achieved by having relatively long intervals between observations (Swihart and Slade; 1985).

2.2 Satellite Imagery

Landsat 5 Thematic Mapper imagery was acquired on May 2, 1998 (Path 43 Row 20 and Path 43 Row 21) from Albert Environment. The large study area expanded into two different Landsat 5 TM images, which were mosaicked together. Because both images were acquired on the same day, they appear seamless in the mosaicked image. Both images were cloud free and there did not appear to be a variation in digital numbers over the water areas, therefore, no atmospheric correction was performed.

The images were ortho-rectified using existing Province of Alberta 1:20,000 road, access coverages and derived DEM. The root mean square error of less than half a pixel (12.5 meters). A subset of the mosaic was then made that incorporated the minimum convex polygon. The subset image represented the caribou study area for the rest of the analysis.

2.3 Habitat Analysis

Habitat analysis was based on correlations found between the GPS caribou location data and the spectral reflectance value of those locations on the Landsat 5 TM

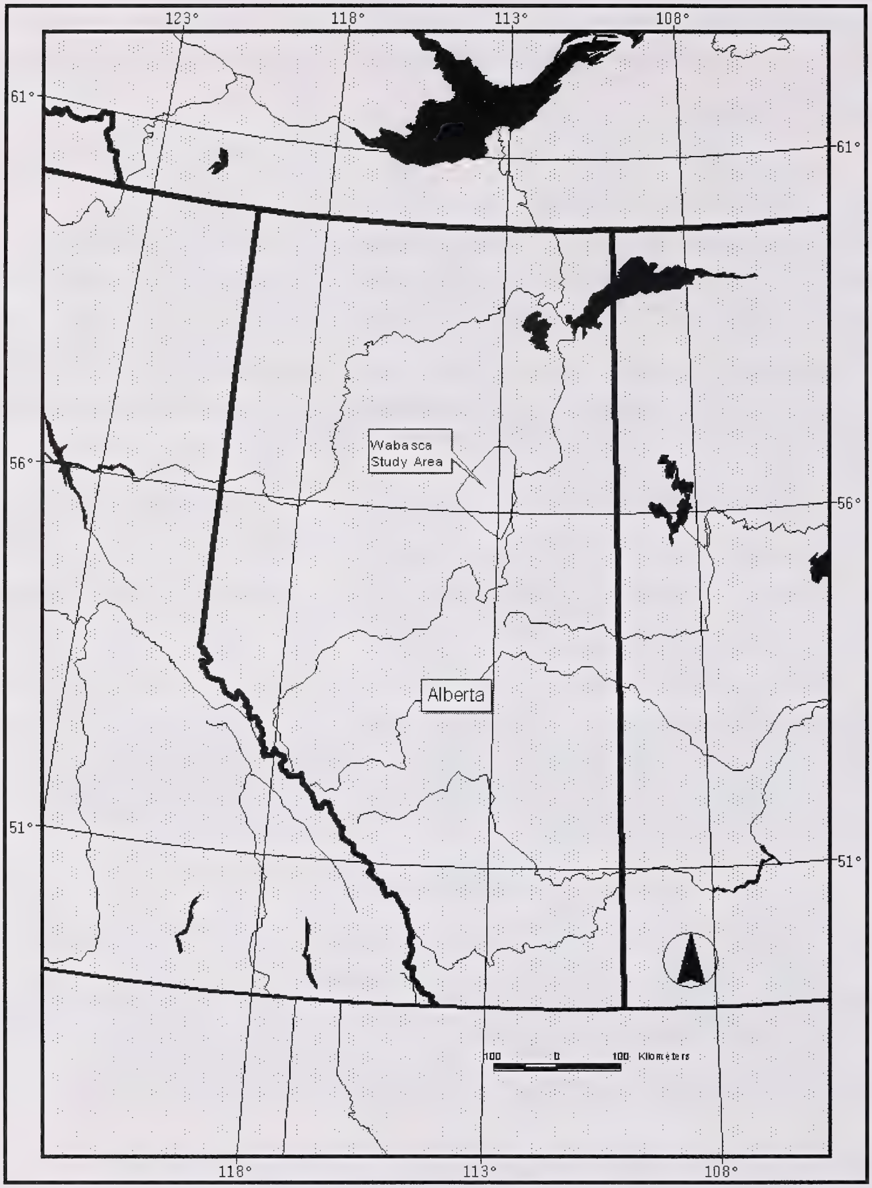


Figure 1. Location of study area and convex polygon using in this report. The convex polygon was defined based on the location of collar GPS readings.

images. These correlations were then used to create a caribou habitat classification that indicates caribou preference and avoidance of spectral classes. Avoidance refers to habitat types where the animal spends less time than expected and preference refers to habitat types where more time is spent in a particular type than by chance alone (White and Garrott 1990).

The decision of which classification method to use was made on the basis that a supervised classification was not possible for this project because ancillary data (e.g. Alberta Vegetation Inventory, field training sites, Alberta Ground Cover Classification, etc.) was unavailable. A supervised classification requires the user to input known training sites or selected areas of spectral similarity, and then allow an algorithm to locate pixels of similar spectral reflectance. However, the goal of this study was to determine if caribou habitat spectral preference could be determined using minimal *a priori* knowledge. That is, to determine if the relationship between woodland caribou locations and spectral reflectance is strong enough that spectral preference and avoidance can be made without user input.

An unsupervised classification was performed on the study area using an ISODATA algorithm unsupervised classification. The ISODATA method is an iterative classifier that performs an entire classification and then recalculates the statistics with each pass. Trials of 10, 15, 20, 25 and 30 classes were examined. A classification using twenty-five classes was chosen as most representative of existing land cover. Twenty-five classes seemed to give the best separation of spectral signatures without needless repetition of similar groupings. For example, when only ten or fifteen classes were used, pixels were grouped into broad spectral classes that did not distinguish areas with enough detail. When thirty classes were used, pixels were separated into different classes, though they appeared to have very closely related spectral signatures and likely represented the same vegetative cover type. Therefore, twenty-five classes were chosen as the optimal number to be used to discern land features without repetition.

The spectral reflectance values within the study area were selected on the basis of caribou occupation within particular pixels. While this process determines caribou habitat preference within a particular area, it is dependent on the presence of collared caribou. The area surrounding the Wabasca study area does not have the use of GPS collared caribou to perform this type of classification. Therefore, the results from the caribou habitat classification (i.e. the Wabasca study area) were used to perform a supervised classification in the surrounding area of one entire Landsat TM satellite image (Path 43 Row 21), an area of 31 450 km^2. A total of 51 training sites were selected from within the study area to be used as training sites for the supervised classification of the Landsat TM image. In order to create a usable map that is of practical use to land managers, a 5x5-majority statistical filter and a minimum mapping unit of eight hectares were applied to the supervised classification.

2.4 Landscape Structure Analysis

The objective of this component of the study is to observe the effects of changing Minimum Mapping Unit (MMU) on caribou habitat and to identify a range of MMUs where different landscape processes react to the change in MMU in a stable and predictable matter. The analysis was performed on filtered images with the following MMUs: 1,2,3,4,5,8, ,10,15,20 and 25 ha MMU. Each landscape was described using the following landscape structure statistics used in the analysis: number of patches, patch density, fractal dimension, the Shannon and the Simpson patch diversity indexes. The following is a description of the key indices used in this study:

a) The Shannon Diversity Index: The Shannon's diversity index (SHDI) based on information theory is defined as (Shannon and Weaver 1949):

$$SHDI = -\sum_{i=1}^{m} (P_i \_ \ln P_i)$$

where $\mathbf{P_I}$ equals the proportion of the landscape occupied by a map class or habitat type i. It is used to measure landscape diversity based on the relative abundance of map classes in a given landscape area. The absolute magnitude of the Shannon's diversity index is not meaningful as an independent measure, but its relative values can be use to evaluate diversity between different landscapes or the same landscape at different times. Values approaching 1 or higher indicate higher diversity of habitat classes in a landscape. Values approaching 0 indicate lower diversity, where a single map class or habitat type dominates throughout the landscape. It must be noted that the Shannon's diversity index is highly sensitive to richness and less so to evenness, therefore rare map classes largely and disproportionately influence the magnitude of the index. As a result, there is a disproportionately large effect on the magnitude of the index influenced by rare map classes.

b) Simpson Diversity Index: The Simpson's diversity index (SIDI) is defined as:

$$SIDI = 1 - \sum_{i=1}^{m} P_i^2$$

where P_i equals the proportion of the landscape occupied by a map class or habitat type i. It is used to measure landscape diversity by representing the index as the probability that any randomly selected patches are from different map classes. Values approaching 1 indicates greater diversity or that there is a very high chance that any two patches selected at random would be from different classes in a landscape. Values approaching 0 indicate lower diversity, where the chance of having two randomly selected patches belonging to different map classes is low. It must also be noted that the Simpson's diversity index are relatively less sensitive to richness than the Shannon's diversity index and thus, place more emphasis and weight on more common map classes.

c) Fractal Dimension: Fractal dimension was calculated both at the landscape level and the patch level. Landscape level fractal dimension was calculated as the slope of a linear regression through data points on a log(Area) vs. log(Perimeter) plot, and plotted vs. MMU. Patch level fractal dimension was calculated for each patch as the log of area divided by the log of the perimeter (log A/log P). The fractal dimension was then plotted versus the area in hectares (logarithmic scale) for each MMU size. The result is a dataset cloud that represents all polygons within the study area that are larger than the corresponding MMU. Patch level fractal dimension was then plotted as a frequency distribution.

d) Statistical Tests: Two statistical tests were used for verification of significance of the results for the different indexes used in this study. The student T-test was used to test whether any two-regression equations were statistically different from one another. The T-test calculates the probability that samples came from the same population. In order to test two regressions, 40 points from each regression were calculated, and the T-test was applied to the two arrays. In order to validate the linear regressions used to calculate fractal dimension, an F-test was also performed on the log (P)-log(A) regression. The F-probability is the one-tailed probability that the variance of two arrays is not significantly different. For every patch represented in the plot, a theoretical value of log (A) was calculated. The matrix of actual log (A) values was then compared to the matrix of theoretical log(A) values by calculating the F-probability. F-probability values for landscape level fractal dimensions were plotted vs. MMU.

3.0 RESULTS

3.1 Regarding Objective No. 1

- Using results for the Wabasca region, spectral classes were extrapolated to the image north of the study area. Results were processed using a supervised classification. All images were merged to produce a final map. Figure 2 to 4 represent the delineated caribou habitat for each selected satellite image. Figure 5 presents the overall caribou habitat for the whole northeast boreal region.
- The removal of caribou locations that were spatially auto-correlated had very little effect on the overall results of the study. In fact, although the percentages of occurrence changed slightly, the preference versus avoidance rules remained exactly the same.
- Table 1 and 2 summarize the results of samples A and B. Table 3 summaries the results using the VHF information. Table 4 presents results of revised samples A and B, which underwent spatial auto-correlation analysis. Also added to the Table 4 are the results of recombining samples A and B together again to represent the entire GPS dataset as well as the results of the VHF dataset.

Table 1. Sample A result from unsupervised classification of Wabasca study area by spectral class. % Available is the percent of that class within the study area. % Used is the percent of only those pixels that contain caribou locations. Standard deviation (_) is of % Used data.

Spectral Class	Area (ha)	Available (%)	Used (%)		Preference
Class 1	25870.4	3.0	0.1	0.3	Avoided
Class 2	25612.4	3.0	0.9	0.9	Avoided
Class 3	31297.9	3.7	1.0	0.9	Avoided
Class 4	35271.3	4.1	2.0	1.8	Avoided
Class 5	17772.3	2.1	0.5	0.4	Avoided
Class 6	48429.5	5.7	4.2	2.5	Avoided
Class 7	44982.6	5.3	6.3	3.3	Preferred
Class 8	44252.6	5.2	5.9	3.3	Preferred
Class 9	28450.3	3.3	1.4	1.0	Avoided
Class 10	25617.8	3.0	1.4	1.2	Avoided
Class 11	58429.3	6.9	14.3	7.7	Preferred
Class 12	45822.3	5.4	8.4	5.1	Preferred
Class 13	39700.4	4.7	5.0	3.3	Avoided*
Class 14	41130.5	4.8	8.1	3.0	Preferred
Class 15	10711.5	1.3	1.4	1.9	Preferred
Class 16	34933.1	4.1	6.8	3.5	Preferred
Class 17	31473.4	3.7	5.1	2.3	Preferred
Class 18	37085.0	4.3	5.0	3.0	Preferred
Class 19	32965.5	3.9	1.9	2.4	Avoided
Class 20	34785.0	4.1	2.0	2.0	Avoided
Class 21	41900.8	4.9	7.0	5.7	Preferred
Class 22	40906.4	4.8	2.8	1.5	Avoided
Class 23	20549.2	2.4	4.8	3.1	Preferred
Class 24	39208.5	4.6	2.8	2.0	Avoided
Class 25	15429.8	1.8	0.8	0.8	Avoided

Class 13 selected as avoided due to higher variance than Sample B.

Table 2. Sample B result from unsupervised classification of Wabasca study area by spectral class. % Available is the percent of that class within the study area. % Used is the percent of only those pixels that contain caribou locations. Standard deviation (_) is of % Used data.

Spectral Class	Area (ha)	% Available	% Used	_	Preference
Class 1	25870.4	3.0	0.2	0.3	Avoided
Class 2	25612.4	3.0	1.3	1.5	Avoided
Class 3	31297.9	3.7	2.0	2.3	Avoided
Class 4	35271.3	4.1	3.0	2.0	Avoided
Class 5	17772.3	2.1	0.6	0.6	Avoided
Class 6	48429.5	5.7	6.9	8.5	Avoided *
Class 7	44982.6	5.3	6.9	3.8	Preferred
Class 8	44252.6	5.2	8.7	3.6	Preferred
Class 9	28450.3	3.3	1.3	0.7	Avoided
Class 10	25617.8	3.0	1.1	0.5	Avoided
Class 11	58429.3	6.9	13.6	6.5	Preferred
Class 12	45822.3	5.4	9.8	6.6	Preferred
Class 13	39700.4	4.7	3.8	1.1	Avoided
Class 14	41130.5	4.8	8.3	4.4	Preferred
Class 15	10711.5	1.3	1.7	1.6	Preferred
Class 16	34933.1	4.1	5.7	2.8	Preferred
Class 17	31473.4	3.7	3.8	2.7	Preferred
Class 18	37085.0	4.3	3.8	2.1	Preferred *
Class 19	32965.5	3.9	1.5	0.9	Avoided
Class 20	34785.0	4.1	1.5	0.9	Avoided
Class 21	41900.8	4.9	4.7	2.6	Preferred
Class 22	40906.4	4.8	2.0	1.3	Avoided
Class 23	20549.2	2.4	4.3	2.1	Preferred
Class 24	39208.5	4.6	2.6	2.0	Avoided
Class 25	15429.8	1.8	1.0	0.8	Avoided

* Denotes different result than from sample A.

Table 3. VHF data result from unsupervised classification of Wabasca study area by spectral class. % Available is the percent of that class within the study area. % Used is the percent of only those pixels that contain caribou locations.

Spectral Class	Area (ha)	Available (%)	Used (%)	Preference
Class 1	25870.4	3.0	0.4	Avoided
Class 2	25612.4	3.0	1.7	Avoided
Class 3	31297.9	3.7	1.3	Avoided
Class 4	35271.3	4.1	3.1	Avoided
Class 5	17772.3	2.1	0.8	Avoided
Class 6	48429.5	5.7	5.6	Avoided
Class 7	44982.6	5.3	6.4	Preferred
Class 8	44252.6	5.2	7.2	Preferred
Class 9	28450.3	3.3	1.2	Avoided
Class 10	25617.8	3.0	1.3	Avoided
Class 11	58429.3	6.9	11.2	Preferred
Class 12	45822.3	5.4	7.4	Preferred
Class 13	39700.4	4.7	3.0	Avoided
Class 14	41130.5	4.8	7.3	Preferred
Class 15	10711.5	1.3	2.8	Preferred
Class 16	34933.1	4.1	6.8	Preferred
Class 17	31473.4	3.7	4.4	Preferred
Class 18	37085.0	4.3	4.4	Preferred
Class 19	32965.5	3.9	2.1	Avoided
Class 20	34785.0	4.1	2.6	Avoided
Class 21	41900.8	4.9	6.2	Preferred
Class 22	40906.4	4.8	3.1	Avoided
Class 23	20549.2	2.4	5.5	Preferred
Class 24	39208.5	4.6	3.2	Avoided
Class 25	15429.8	1.8	1.0	Avoided

Table 4. Summaries of availability versus use datasets. "Revised" datasets have undergone spatial auto-correlation analysis. Entire GPS dataset is combination of sample A and sample B (36 animals in total).

Spectral Class	Study Area Available (%)	Sample A Used (%)	Sample A Used (%) (Revised)	Sample B Used (%)	Sample B Used (%) (Revised)	Entire GPS Dataset Used (%)	VHF Dataset Used (%)
Class1	3.0	0.1	0.1	0.2	0.2	0.1	0.4
Class2	3.0	0.9	0.9	1.3	1.3	1.1	1.7
Class3	3.7	1.0	1.1	2.0	1.8	1.4	1.3
Class4	4.1	2.0	2.2	3.0	3.2	2.7	3.1
Class5	2.1	0.5	0.6	0.6	0.8	0.7	0.8
Class6	5.7	4.2	4.1	6.9	6.0	5.0	5.6
Class7	5.3	6.3	5.9	6.9	6.7	6.3	6.4
Class8	5.2	5.9	5.5	8.7	8.3	6.9	7.2
Class9	3.3	1.4	1.7	1.3	1.6	1.7	1.2
Class10	3.0	1.4	1.6	1.1	1.4	1.5	1.3
Class11	6.9	14.3	11.4	13.6	11.4	11.4	11.2
Class12	5.4	8.4	8.0	9.8	9.0	8.5	7.4
Class13	4.7	5.0	4.8	3.8	4.3	4.5	3.0
Class14	4.8	8.1	7.9	8.3	7.9	7.9	7.3
Class15	1.3	1.4	1.7	1.7	1.9	1.8	2.8
Class16	4.1	6.8	7.3	5.7	6.3	6.8	6.8
Class17	3.7	5.1	5.7	3.8	4.1	4.9	4.4
Class18	4.3	5.0	5.3	3.8	4.0	4.7	4.4
Class19	3.9	1.9	2.0	1.5	1.7	1.8	2.1
Class20	4.1	2.0	2.2	1.5	1.7	1.9	2.6
Class21	4.9	7.0	6.7	4.7	5.2	5.9	6.2
Class22	4.8	2.8	3.4	2.0	2.3	2.8	3.1
Class23	2.4	4.8	5.3	4.3	4.9	5.1	5.5
Class24	4.6	2.8	3.3	2.6	2.9	3.1	3.2
Class25	1.8	0.8	1.0	1.0	1.3	1.1	1.0

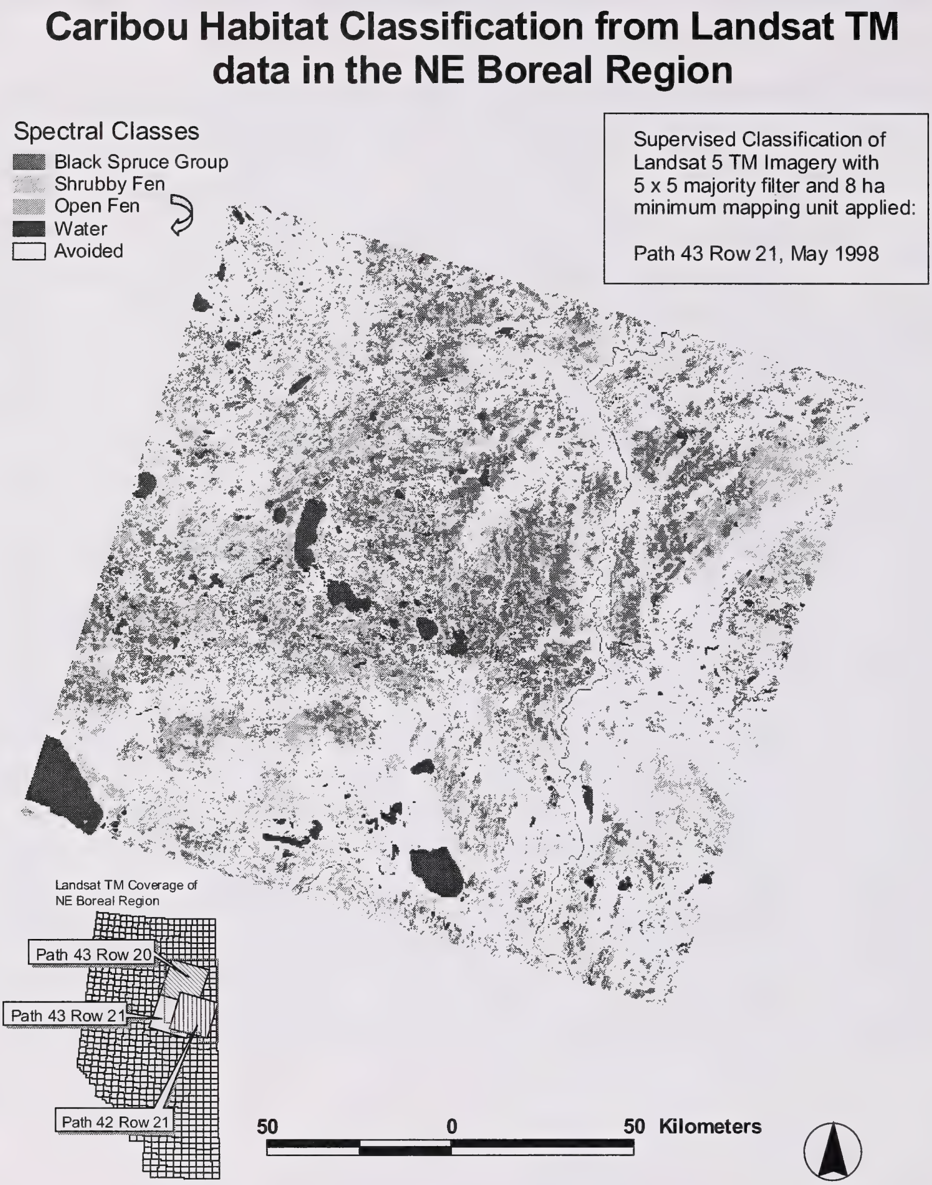


Figure 2. Supervised classification of preferred spectral classes in Landsat TM scene (path 43 row 21).

Caribou Habitat Classification from Landsat TM data in the NE Boreal Region

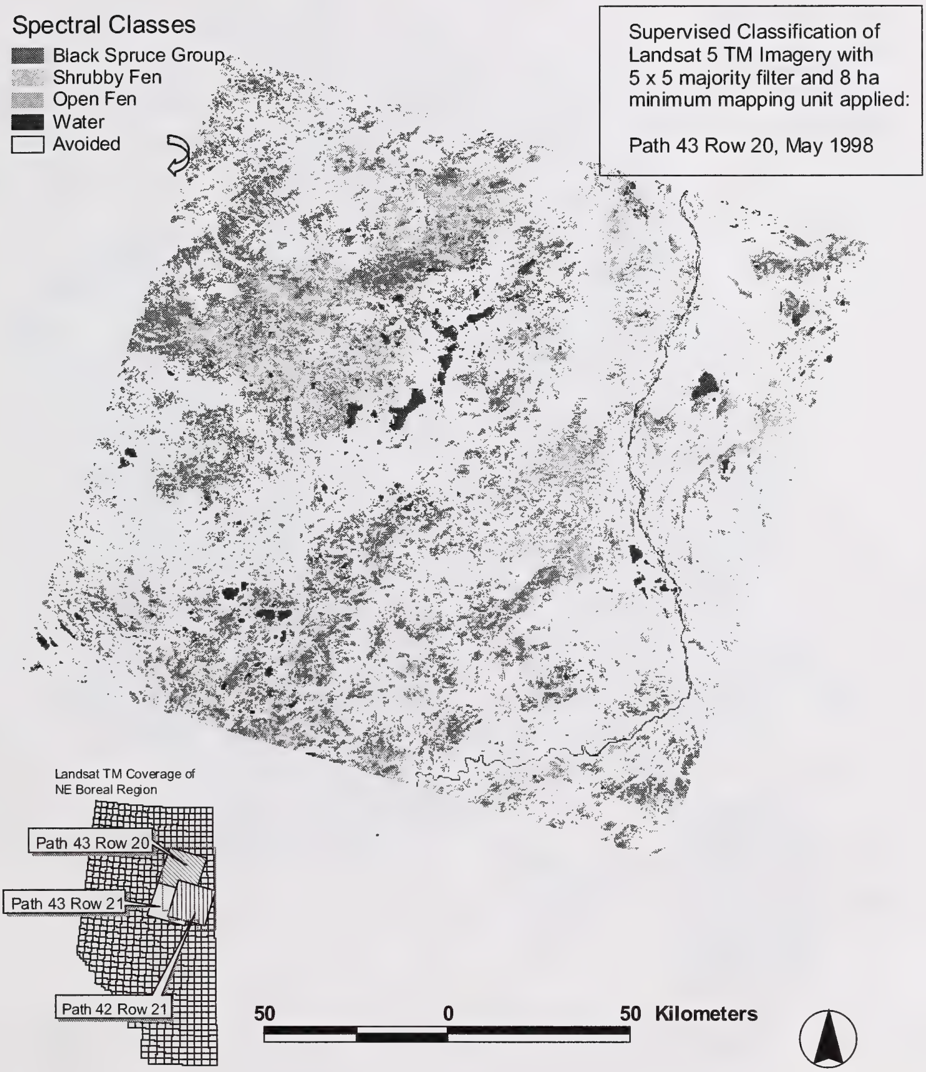


Figure 3. Supervised classification of preferred spectral classes in Landsat TM scene (path 43 row 20).

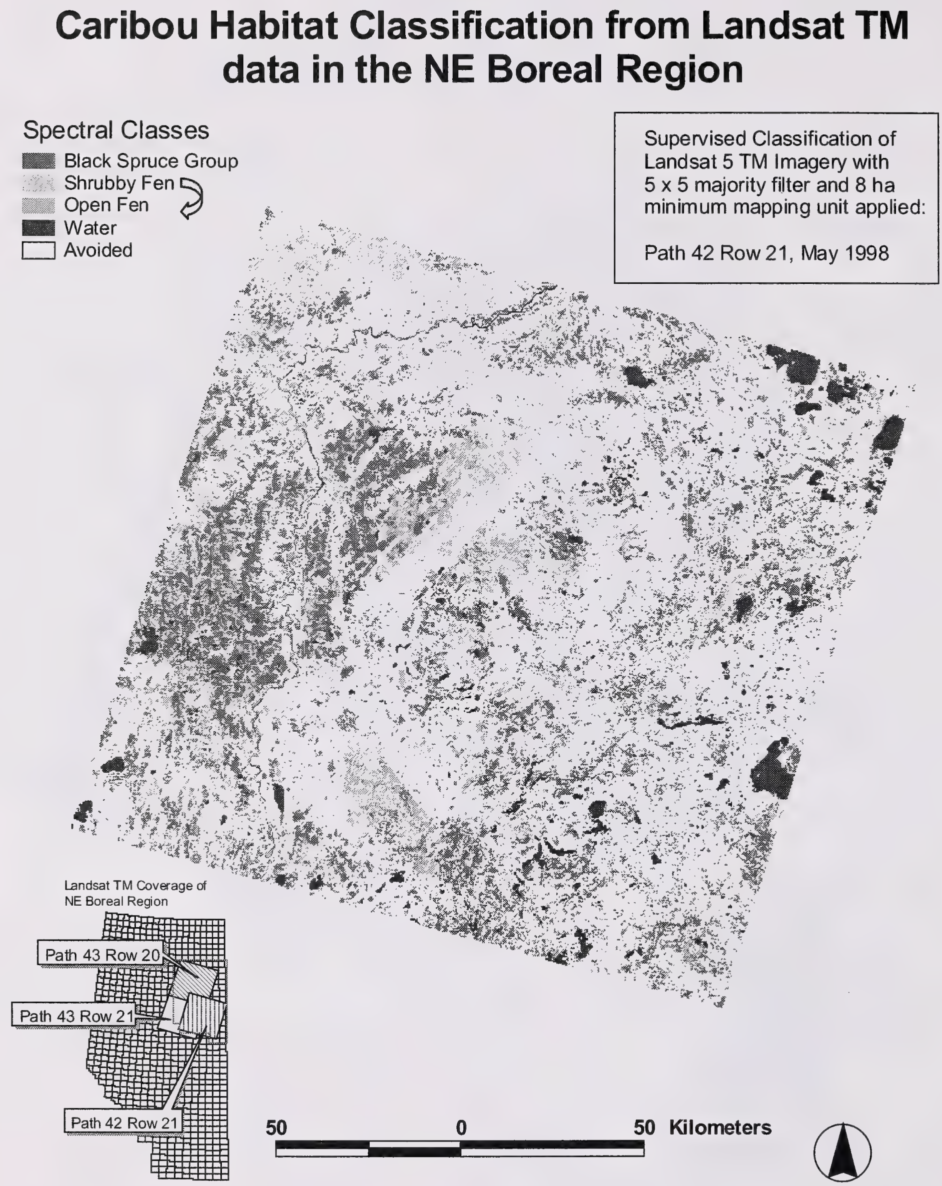


Figure 4. Supervised classification of preferred spectral classes in Landsat TM scene (path 42 row 21).

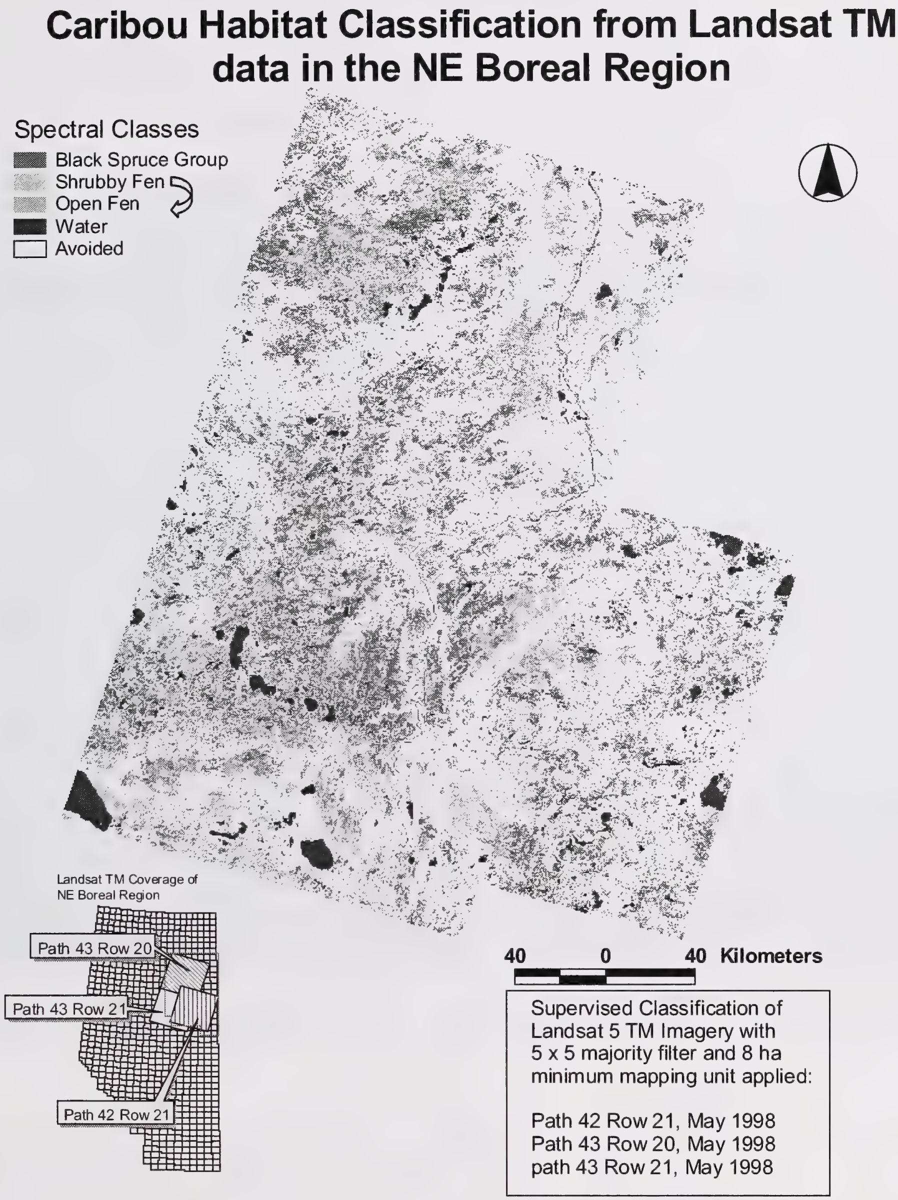


Figure 5. Supervised classification of preferred spectral classes in Landsat TM scene (mosaic of all three images used in study).

3.2 Regarding Objective No. 2

- AVI data sets, because of their high resolution and data richness, do not provide conclusive results regarding the nature of land cover on the spectral classes defined as preferred or avoided.
- Our results indicate that AVI is not adequate to accomplish the objectives of this project.
- We decided to explore the role that Alberta Ground Cover Characterization (AGCC) products can play on class description.
- Our results indicate that AGCC provides more aggregated information to allow for accurate labeling of caribou preferred classes. There is a close correlation between initial labels and the AGCC classes (Figures 6 and 7)

3.3 Regarding Objective No. 3

- The VHF dataset results correlate extremely well with the sample A dataset. A regression analysis plotting the analysis data (sample A) to the VHF data shows a r^2 value of 0.9535. The chi test performed between the two samples resulted in a value of 0.99997. Again, although the percentages of occurrence changed slightly, the preference versus avoidance rules remained exactly the same (Figure 8).

3.4 Regarding Objective No. 4

- Our analysis of MMU indicates that the caribou landscape is sensitive to changes on MMU between 1 ha and 7 ha. This sensitivity is consistent with all landscape fragmentation statistics (Figures 9a and b).
- Results using F-Test indicate that a change in landscape structure can be identified at 7.5 ha (Figures 10a to 10b). Landscapes under this threshold are extremely dynamic and significant changes on landscape structure are observed under 7.5 ha. The landscape becomes stable after 7.5 ha MMU.

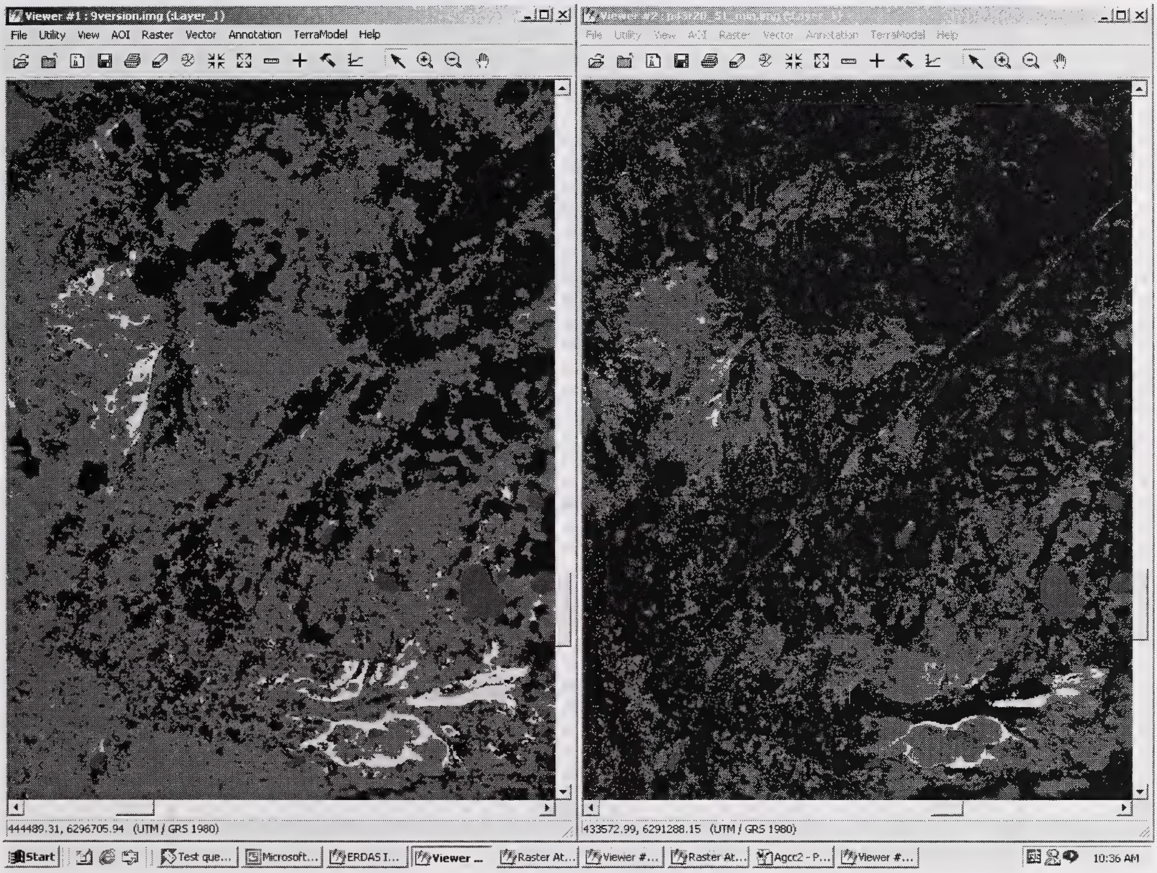


Figure 6. Example of using AGCC to identify caribou preferred classes. AGCC (left) can be used to identify spectral class vegetation types (right).

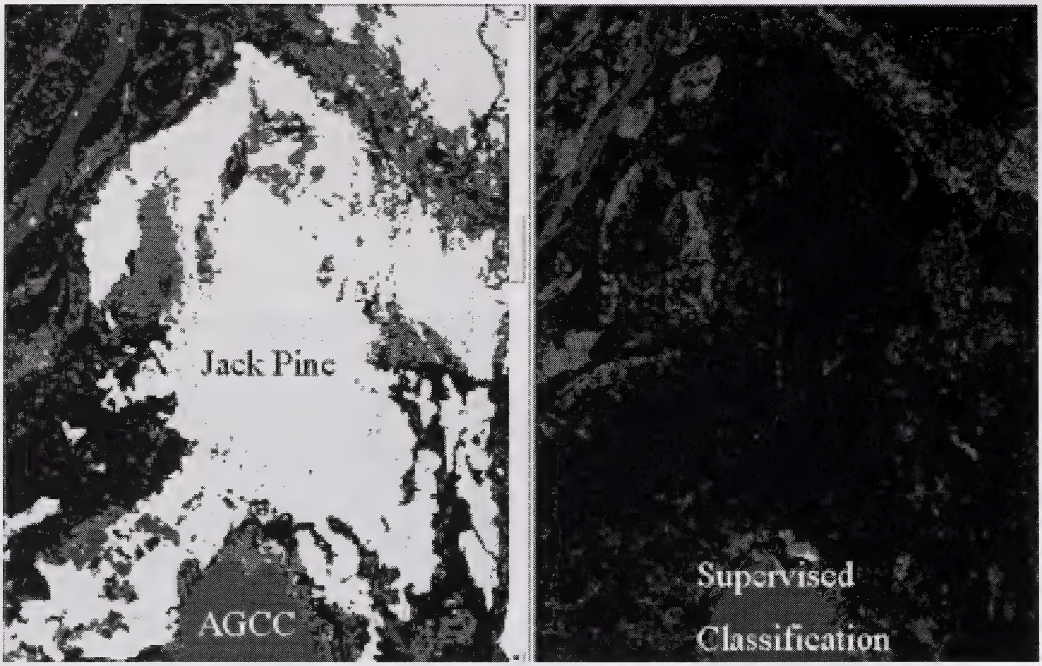


Figure 7: The AGCC classification (left) identifies jack pine in areas that were selected as avoided caribou habitat classes (right).

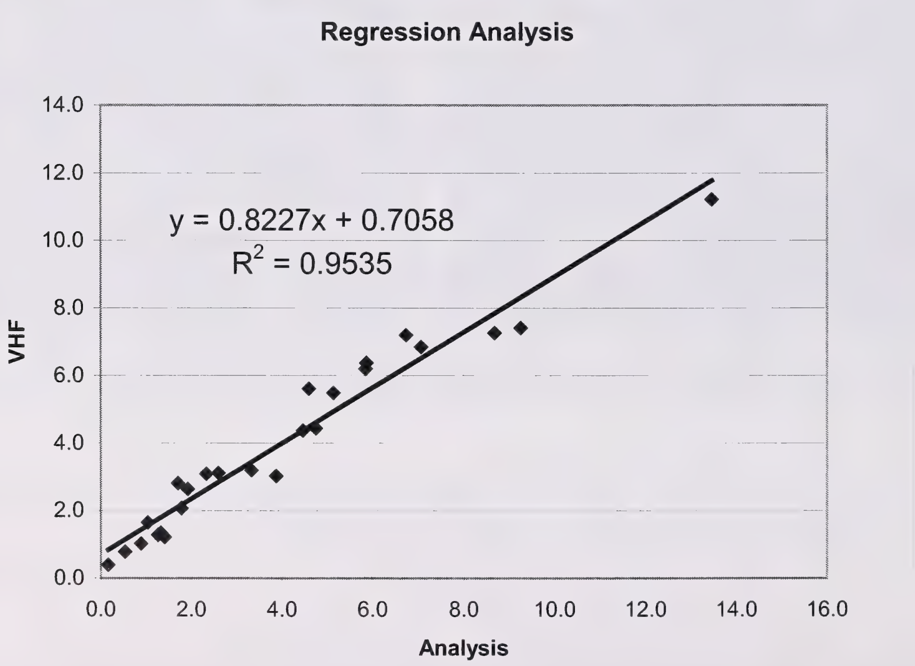
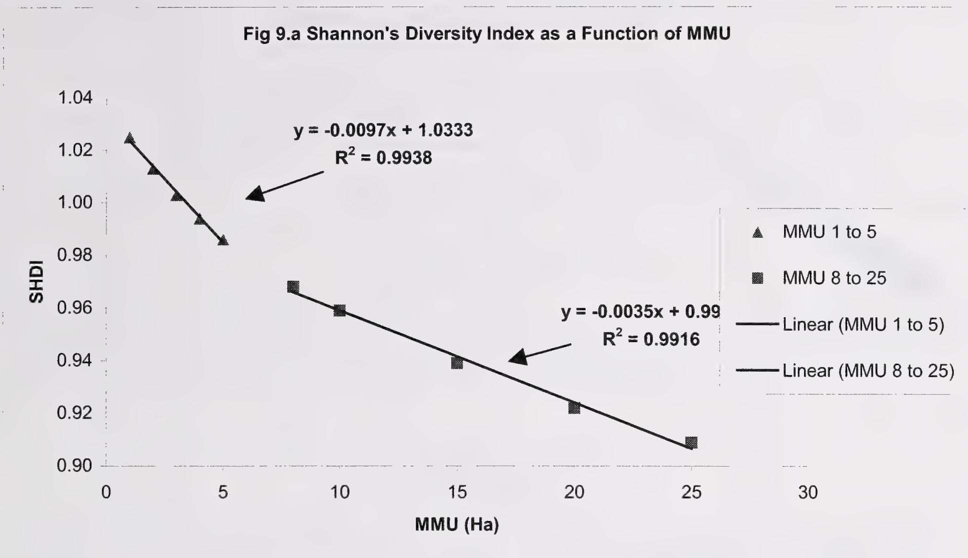


Figure 8. Regression analysis showing the correlation between the analysis (Sample A) and the VHF dataset.



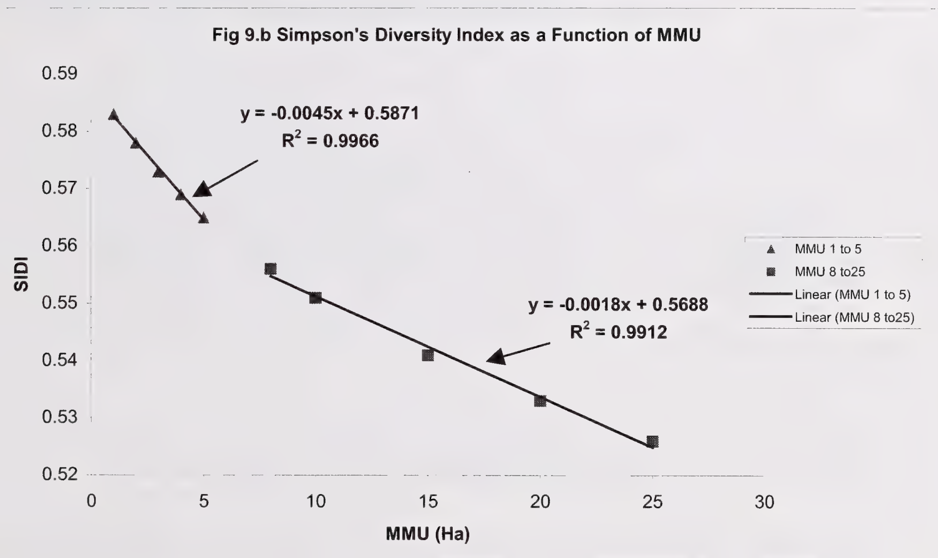


Figure 9. Sensitivity of caribou habitat to minimum mapping unit changes. (a) Shannon Diversity Index and (b) Simpson Diversity Index.

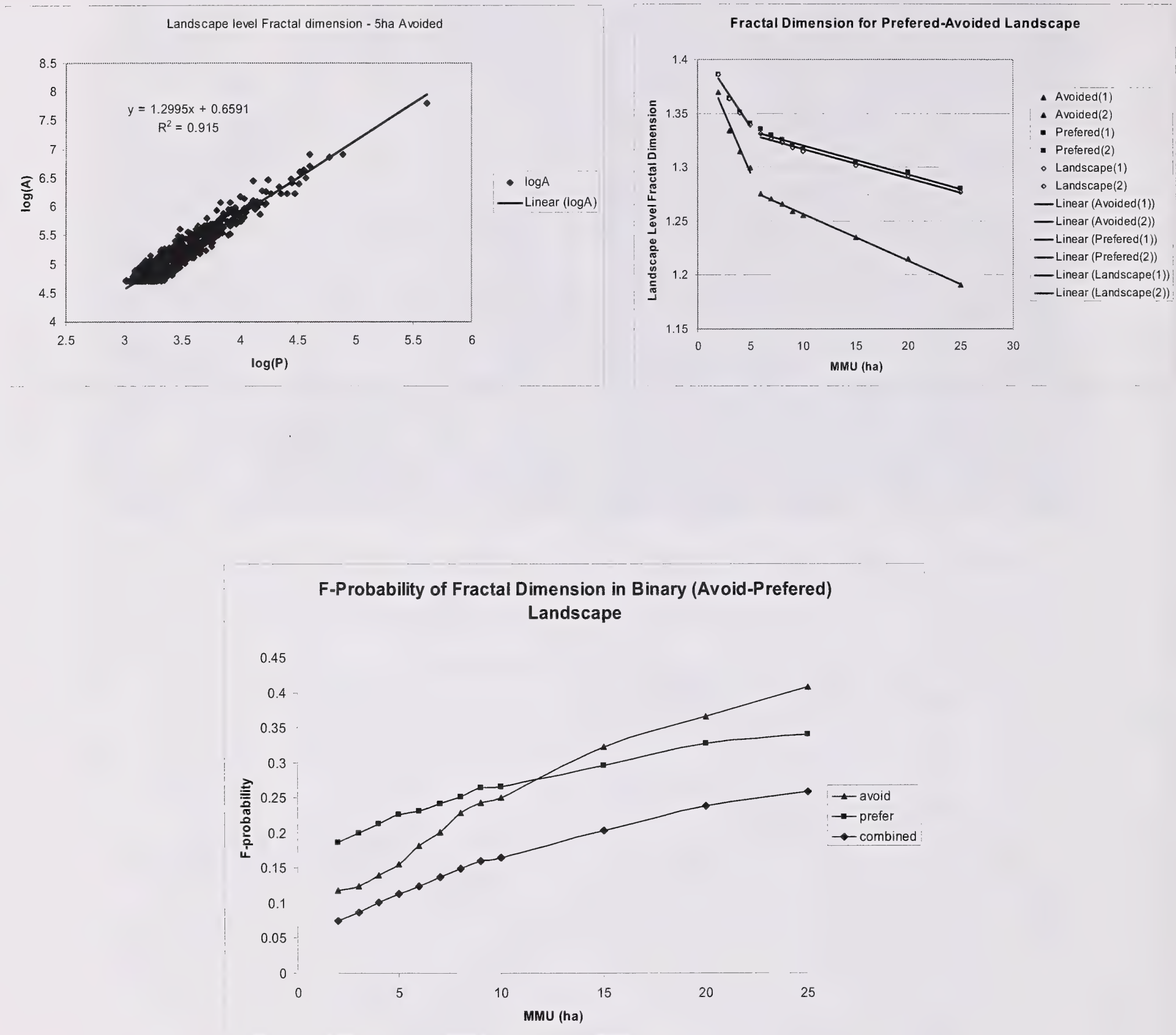


Figure 10. Landscape level fractal dimension (D) analysis. (a) D is calculated as the slope of the linear regression of Log (A) vs. Log (P), (b) D vs. MMU, showing a break point at 6 ha., and (c) F probability of fractal dimension regressions, showing increase significance of linear regression with increasing MMU.

- Landscape structure analysis applied to fractal dimension indicates that the landscape becomes more generalized as MMU increases.
- Landscape structure analysis indicates that the Shannon and Simpson Diversity indexes are extremely sensitive to changes on landscape structure. A t-test indicates that Shannon and Simpson's indices present different behaviors around the same areas where changes on landscape structure of observed for fractal dimension.

3.5 Regarding Objective No. 5

- Our results indicate that the current spatial distribution of points and specifically the limited number of observations does not provide the necessary level of information to define caribou habitats based on spectral reflectance classes for the CLAWR at this time.

3.6 Regarding Objective No. 6

- Results from the Wasbasca and CLAWR were extrapolated to the remaining areas using a supervised classification approach. Images were merged and a full coverage for the NE Boreal region has been created (Figure 5).

4.0 RECOMMENDATIONS AND FUTURE WORK

- Maps with MMU less than 8 ha must not be used for distribution. A MMU of 10 ha is recommended based on our landscape structure analysis.
- The number of VHF points for the CLAWR is producing inconclusive results. The number of sampling points as well as their distribution in the landscape does not allow for an accurate estimate of the extension of the habitat using the spectral dimension / satellite methodology developed in this study.
- The AGCC developed data sets are useful for the identification of preferred caribou habitats.
- Problems are still present in the identification of individual spectral classes that may be of importance for caribou habitat. Specifically there is a need to further develop the identification of classes such as Open and Shrubby Fens, which seems to be too small to be identified by Landsat TM.
- We recommend that a further study for a selected area must be developed using IKONOS hyperspectral data. Because of the high spatial resolution of IKONOS the several of the questions regarding the preferred or avoided use of specific classes such as Open and Shrubby Fens can be further evaluated.
- Further analysis must be performed using other remote sensing platforms. We recommend extrapolating the study to use MODIS level 1B data with a spatial resolution of 250 and 500 meters. Data developed in this study linked to MODIS (hyperspectral data) will help to enhance the available data sets as well as to allow for full integration of the Wabasha and CLWR at the same time.

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