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Characterizing woodland caribou habitat in sub-boreal and boreal forests

Chris J. Johnson¹, Nancy D. Alexander, Roger D. Wheate^{*},
Katherine L. Parker

*Faculty of Natural Resources and Environmental Studies, University of Northern British Columbia,
3333 University Way, Prince George, BC, Canada V2N 4Z9*

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Abstract

Woodland caribou (*Rangifer tarandus caribou*) are sensitive to changes in understory vegetation resulting from forest harvesting and are, therefore, of special concern for foresters and habitat biologists. Effective management of this species requires reliable habitat inventories which, because of the large heterogeneous areas over which caribou range, can be costly. We used Landsat Thematic Mapper (TM) imagery and digital elevation data to identify 23 vegetative cover types across the 5100 km² range of the Wolverine caribou herd of northcentral British Columbia, Canada. The classification was augmented with available geographical information system (GIS) data for a total of 27 cover types. We achieved an overall accuracy of 76.7% based on known ground samples; however, accuracy varied according to cover type. Considering the size of the study area, the procedure we employed was relatively cost effective and efficient. We discuss the advantages of such an approach for wildlife-habitat studies reliant on large-scale vegetation maps.

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1. Introduction

Across North America, woodland caribou (*Rangifer tarandus caribou*) have become a high priority species for management (Cumming, 1992). Historical trends of declining populations or extirpated herds have necessitated management schemes that will not only conserve and stabilize existing populations, but possibly enhance others (Edmonds, 1988). In British

Columbia (BC), Canada, a demand for merchantable timber has led to a heightened awareness of the conflict between human encroachment and the habitat requirements of caribou. To meet the needs of both caribou and industry, information on the habitat requirements and population dynamics of caribou is essential.

Identification of vegetation communities that may constitute habitat is a necessary requirement of most research projects or management schemes designed to understand or conserve large-ranging species. In BC, forest inventory data has traditionally served as the basis for examining caribou–habitat relationships (e.g. Apps et al., 2001) and for implementing small-scale operational and large-scale planning objectives for

^{*} Corresponding author. Tel.: +1-250-960-5865.

E-mail address: wheate@unbc.ca (R.D. Wheate).

¹ Present address: Department of Biological Sciences, University of Alberta, Edmonton, Alta., Canada T6G 2E9.

caribou. Those data are spatially represented at a scale of 1:20,000; features typically related to caribou ecology include canopy species and closure, site productivity, stand age, and stocking density. In some areas of the province, however, the inventory is out of date or is of inconsistent quality for analyses and management efforts conducted at the scale of individual patches. Biologists are also forced to use forest stand characteristics to generate ecological associations with assumed relevance to caribou. Furthermore, areas that are unproductive for forest species are typically not mapped (e.g. alpine habitats). As a replacement, terrestrial ecosystem mapping (TEM) was conceived to capture the ecological associations of vegetation, soils, local and regional climatic conditions, and the resulting relationships with wildlife habitat (Resources Inventory Committee, 1998). High costs and lengthy completion times have hindered the implementation of TEM across the province.

Classification of Landsat Thematic Mapper (TM) imagery in conjunction with readily available ancillary information such as digital terrain data may provide a relatively low-cost alternative for mapping vegetative communities that serve as wildlife habitat. The technique has been applied to species such as muskox (*Ovibos moschatus*), bison (*Bison bison*), whitetail deer (*Odocoileus virginianus*) and waterfowl, and can be especially cost effective when considering the large areas over which species such as woodland caribou range (Ormsby and Lunetta, 1987; Ferguson, 1991; Matthews, 1991; Morrison, 1997). We assessed the utility of Landsat TM imagery and ancillary geographical information system (GIS) data to accurately identify vegetation communities with ecological meaning to caribou–habitat relationships in northcentral BC. Our results have application to other boreal and sub-boreal systems and demonstrate the relative ease and reliability of using remote sensing to identify vegetation communities for conservation research and management across large study areas.

2. Materials and method

2.1. Study area

The 5100 km² area chosen for study was that used by the Wolverine herd (Heard and Vagt, 1998), located

approximately 250 km northwest of Prince George, BC (Fig. 1). The terrain varies, from valley bottoms at approximately 900 m to alpine summits at 2050 m, and is characterized by numerous vegetation associations resulting from diverse topography, soils, and succession. Forest types below 1100 m have been influenced extensively by wildfires and are dominated by lodgepole pine (*Pinus contorta*), white spruce (*Picea glauca*), hybrid white spruce (*P. glauca* × *Picea engelmannii*), and subalpine fir (*Abies lasiocarpa*). Between 1100 and 1600 m, a moist cold climate prevails with forest types consisting primarily of Engelmann spruce (*P. engelmannii*) and subalpine fir. Elevations above 1600 m are alpine tundra and are distinguished by gentle to steep windswept slopes vegetated by shrubs, herbs, bryophytes, and lichens with occasional trees in krummholz form (Meidinger and Pojar, 1991).

2.2. Data acquisition and classification

In 1997, we conducted a review of available vegetation and ecological mapping suitable for assessing the movements and habitat relationships of the Wolverine caribou herd. Existing sources were found to be inaccurate or were of insufficient area to meet project objectives (C. Johnson, unpublished data). Relative to conventional approaches dependent on aerial photographs and extensive field investigations, the most cost-effective option was to use Landsat TM imagery to classify the vegetation communities and other cover types found across the caribou range.

We developed an initial stratification of cover types with potentially unique spectral qualities using the legend and associated ecological data from a previous mapping project (McKenzie, 1993) that covered a portion of the study area. A fixed-wing aircraft was used to assess the study area and collect oblique photographs of vegetation associations. From 9 June to 15 July 1998, we visited and recorded the location and characteristics of suitable patches of vegetation to serve as training sites for the classification procedure. Sampling frequency for each predefined cover type was dependent on heterogeneity of vegetation (i.e. spectral reflectance).

A seven band Landsat TM dataset was acquired for 22 August 1992 (track 50/frame 21). This date was selected to optimize the photosynthetic potential of the

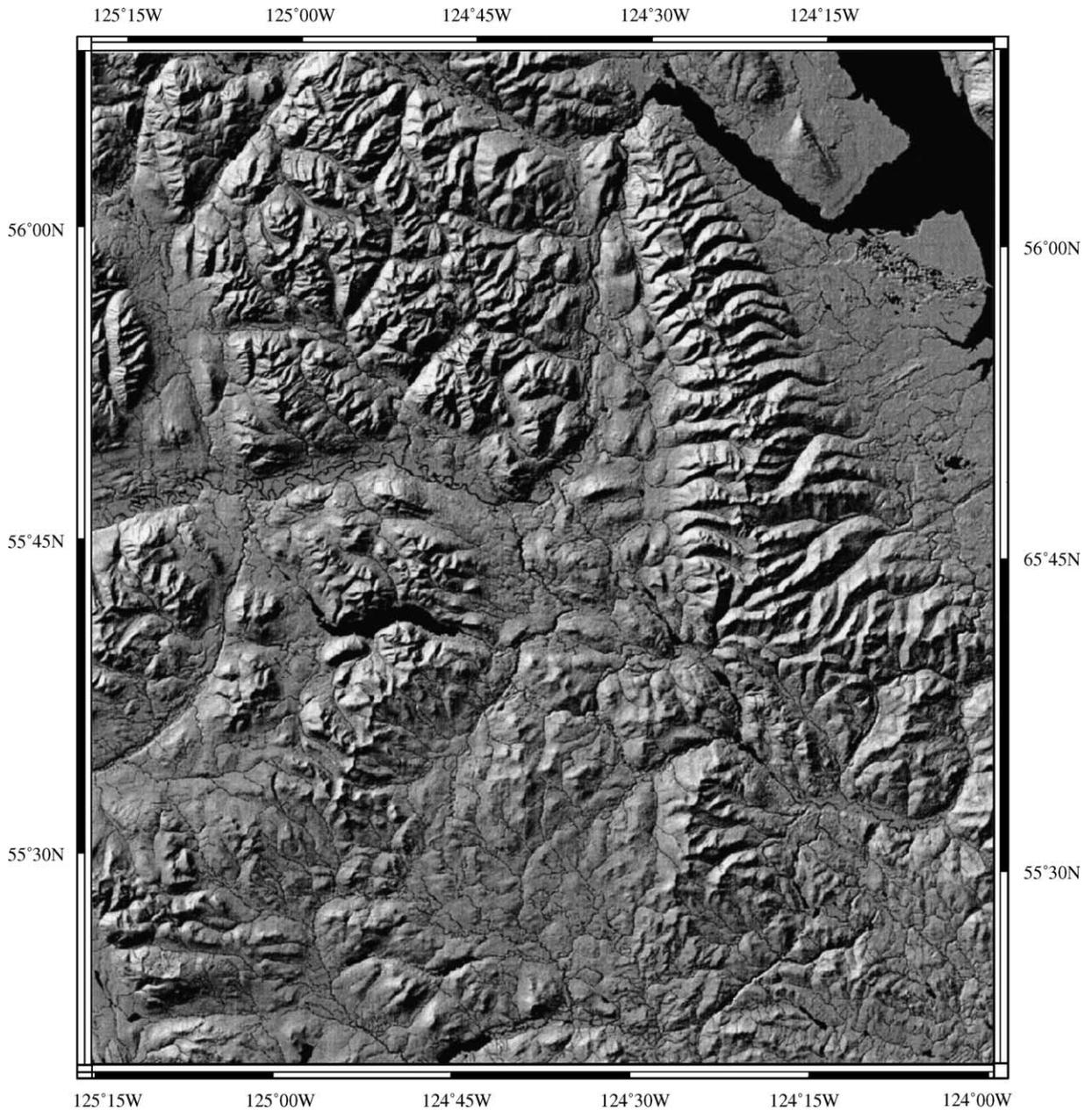


Fig. 1. The Wolverine caribou study area in northcentral BC, Canada (shaded relief model from BC TRIM digital data).

vegetation while minimizing snow cover at high elevations. Forest companies with cutting rights in the study area provided digital files of clearcut boundaries. A digital elevation model generated from 1:20,000 provincial Terrain Resource Inventory Management

(TRIM; [British Columbia Ministry of Crown Lands, 1990](#)) data was used to produce layers of slope and incidence. Roads, trails, lakes, and rivers were also extracted from the TRIM data. The study area was clipped from the full Landsat scene and georectified

using 57 ground control points of road intersections and river junctions selected from the TRIM thematic data (RMS error = 0.88 pixel; Kardoulas et al., 1996).

We used a supervised maximum-likelihood procedure (Lillesand and Kiefer, 1994) and a dataset consisting of Landsat bands TM 3 (Red), TM 4 (near infrared), TM 5 (mid-infrared), elevation, slope, incidence, and a normalized difference vegetation index (NDVI) to classify the image. The NDVI channel is a composite of TM 4 and TM 3 and gives an estimate of green biomass. Two hundred and seventy-eight training sites defined the spectral qualities of the identified cover types. Training classes derived from these sites were analyzed and merged where there was poor discrimination. Following classification, we used a modal filter to remove single isolated pixels and aggregate small patches below a minimum of 4 ha.

A second set of independent ground-truth points was used to assess the accuracy of the classification. Because of the large study area and lack of road access we did not adopt a stratified or truly random strategy for sampling truth points. Instead, 473 independent assessment locations were taken from the original field data of the McKenzie project (1993), vegetation data gathered during investigations of caribou foraging sites (Johnson et al., 2001), visits to sites accessible by road, and identifiable homogenous patches identified on monochrome air photos and oblique color slides. We believe that our truth points were representative of the cover types found across the study area and that variation in data sources controlled for systematic biases in sampling. We identified ground-truth sites as one of the classification cover types and based on correspondence with our classified image calculated several measures of accuracy (Congalton et al., 1983). Overall accuracy represents the percentage of truth sites that correspond with the classified image. Producer's accuracy is a measure of classified pixel omission from the correct cover type while user's accuracy is a measure of commission or false inclusion of pixels within the specified cover type. The kappa (κ) statistic represents the improvement in the observed classification over one based on chance.

Landscape features of a small area (approximately two to three pixels), such as roads or minor waterways, can be difficult to capture with Landsat satellite

imagery and may be lost during post-classification smoothing. To represent those features, we extracted roads, trails, lakes, and rivers from the TRIM data and integrated them with the final map. Since the imagery was approximately 6 years old, clearcut boundaries recorded as of 1996 were applied to the final image. Classification and image manipulation procedures were performed with Easi/Pace software (PCI Geomatics, Richmond, Ont., Canada).

3. Results and discussion

Using a supervised classification we identified 23 cover types (Table 1). Four additional types were created following the merging of the supervised classification and the TRIM lakes, roads/trails, rivers, and clearcut boundary GIS coverages. We achieved an overall classification accuracy of 76.7% and a κ statistic of 0.748 (Table 2). The κ statistic indicates that the observed classification was nearly 75% better than chance. Our results were similar to other classifications of boreal forests across variable terrain. For example, Franklin and Moulton (1990) achieved an accuracy of 77.6% when conducting a supervised classification using a Landsat image in conjunction with a digital elevation model of a 250 km² area of southwest Yukon, Canada. Our accuracy values were, however, variable across cover types. Pine–lichen had a user's accuracy of 98.6%, whereas the spruce cover type had an accuracy of only 50% (Table 2). For that cover type, black spruce, Abies–spruce, spruce–pine, and pine–black spruce were mistakenly classified as spruce (i.e. errors of commission; Table 2). Development and interpretation of the accuracy assessment was limited by small sample sizes of ground-truth sites for some cover types. We could not confidently identify any assessment sites for the Abies type and had small sample sizes for other cover types including alpine–shrub, alpine–moist/shrub, and rockfall. Measures of accuracy for cover types with few ground-truth sites are less reliable and likely highly variable depending on the sample used for assessment.

Typically, underrepresented cover types were difficult to identify with air photos or color slides and were inaccessible by road. Recommendations on sample size vary, but Congalton (1991) suggested that the minimum number of samples per cover type should

Table 1
Cover types produced from a supervised classification of a Landsat TM image of the Wolverine caribou study area

Cover type	Area (ha)	Description ^a
Aspen	37,163	Shrub or closed stands of <i>Populus tremuloides</i> that may be associated with <i>P. contorta</i>
Pine	49,804	Dominated by <i>P. contorta</i> , but may occur with a component of <i>P. mariana</i> or <i>P. engelmannii</i> × <i>P. glauca</i> in older stands; understory is characterized by feather mosses
Spruce	46,357	Dominated by <i>P. engelmannii</i> × <i>P. glauca</i> , but may be a minor component of <i>P. mariana</i> or <i>P. contorta</i>
Lake	28,345	Permanent water bodies
Avalanche track	1,993	Active avalanche chutes and associated colluvial fans; shrub-dominated with herbaceous openings
Alpine–little vegetation	9,574	Wind-swept alpine ridge-tops or upper slopes with little vegetative cover
Alpine–shrub	13,780	Moderate to steep alpine slopes with extensive cover of <i>Betula glandulosa</i>
Black spruce	14,248	Water table at or near the surface consisting of open stunted forests of <i>P. mariana</i>
Sedge bog	21,834	Shrub/sedge and forb dominated wetlands on depression landscapes with high water tables
Shrub bog	12,893	Drier variant of sedge bog with ~50% cover of <i>B. glandulosa</i> or <i>Salix</i> spp. and stunted <i>P. mariana</i>
Alpine–moist shrub	289	Moist meadows typically in alpine bowls or cirques
Rockfall	9,036	Steep rocky terrain with sparse vegetation and lichen-dominated cover
Krummholz	45,062	Shrub cover of subalpine fir on gentle to moderate slopes (parkland)
Alpine–grass shrub	1,935	Alpine areas with deep soil on gentle to moderate slopes; grass-dominated cover; <i>Stereocaulon</i> , <i>Cetraria</i> , and <i>Cladina</i> spp. found in less productive openings
Abies–spruce	99,841	Mid-elevation stands on moderate to steep slopes dominated by <i>A. lasiocarpa</i> and <i>P. engelmannii</i>
Spruce–pine	29,371	Stands at lower elevations consisting of <i>P. engelmannii</i> × <i>P. glauca</i> and <i>P. contorta</i> ; poorly to moderately developed shrub and herb layers
Bedrock/no vegetative cover	12,984	Rocky terrain with sparse vegetation restricted to pockets of soil; lichen-dominated cover of <i>Umbilicaria</i> , <i>Cetraria</i> , and <i>Cladina</i> spp.
Pine–black spruce	49,224	Older <i>P. contorta</i> – <i>P. mariana</i> stands found on level to moderate slopes; associated with patches of <i>Cladina</i> and <i>Cladonia</i> spp., but characteristically feather mosses
Cottonwood	1,279	Active floodplains dominated by <i>P. balsamifera</i> , and <i>Salix</i> spp.
Abies	7,252	Mid-elevation stands on moderate to steep slopes dominated by <i>A. lasiocarpa</i>
Abies–pine	21,257	Dry shedding ridge tops and mid-elevation stands found on moderate to steep slopes composed of open stands of <i>A. lasiocarpa</i> and <i>P. contorta</i> ; <i>Cladina</i> and <i>Cladonia</i> spp. found on dryer sites
Pine–lichen	19,949	Level glaciofluvial terraces and other features with well-drained soils that support stands of <i>P. contorta</i> and an understory of <i>Cladina</i> and <i>Cladonia</i> spp.
Abies–spruce–pine	110,238	Mid-elevation stands of <i>A. lasiocarpa</i> , <i>P. engelmannii</i> , and <i>P. contorta</i> found on moderate to steep slopes
Clearcut	51,965	Areas recently harvested (<20 years) and at an early stage of successional development
River	19,082	Moving watercourses
Road/trail	5,220	Roads and trails primarily used for motor vehicle access
Anthropogenic	25	Agricultural lands or areas disturbed by placer mining

^a For a more complete description of cover types, see Johnson (2000).

range from 75 to 100. In our study, this would have required up to 2300 independent, identifiable, and homogenous locations. By that standard, our accuracy assessment was considered preliminary and forced us to adopt a conservative interpretation of the final classified image.

We did not perform an accuracy assessment of the TRIM lakes, roads/trails, and rivers, but relative to the Landsat-derived cover types are confident in their associated planimetric accuracy. Terrain Resource Inventory Mapping is conducted at a scale (1:20,000)

larger than the resolution of Landsat imagery (~1:50,000) and 90% of all well-defined planimetric features are within 10 m of their true position (British Columbia Ministry of Crown Lands, 1990). We are uncertain of the practices or accuracy standards used to survey and digitize the clearcut boundaries. In several locations, we observed boundaries that extended one to two pixels beyond the edge of clearcuts found on the classified image. This error of commission was likely less than would result from classifying clearcuts using a spectral signature that coincided with other deciduous

Table 2
Classification accuracy for individual cover types resulting from a supervised classification of the Wolverine caribou study area^a

Cover type ^b	Producer's accuracy (%)	User's accuracy (%)	κ	No. of sites
Aspen	93.9	75.6	0.738	33
Pine	82.4	93.3	0.925	51
Spruce	68.8	50.0	0.483	16
Avalanche track	71.2	97.4	0.970	52
Alpine–litter vegetation	84.6	91.7	0.909	39
Alpine–shrub	50.0	50.0	0.494	6
Black spruce	52.4	61.1	0.593	21
Sedge bog	76.5	100	1.000	17
Shrub bog	93.3	90.3	0.897	30
Alpine–moist shrub	100	100	1.000	1
Rockfall	100	77.8	0.774	7
Krummholz	87.5	71.8	0.698	32
Alpine–grass shrub	75.0	85.7	0.855	8
Abies–spruce	28.6	40.0	0.391	7
Spruce–pine	62.5	76.9	0.761	16
Bedrock/no vegetative cover	66.7	33.3	0.329	3
Pine–black spruce	65.0	38.4	0.355	20
Cottonwood	77.8	87.5	0.873	9
Abies	NA ^c	NA	NA	NA
Abies–pine	100	33.3	0.332	1
Pine–lichen	87.7	98.6	0.983	81
Abies–spruce–pine	68.8	78.6	0.778	16
Anthropogenic	100	100	1.000	7

^a Overall accuracy was 76.7% with a κ statistic of 0.748.

^b See Table 1 for description of cover types.

^c Insufficient number of ground-truth sites to calculate accuracy assessment.

cover types. Augmenting the classified image with ancillary GIS data enhanced the interpretability and usefulness of the final map.

To reduce uncertainty, we grouped those cover types with poor accuracy statistics (Table 2) or with few assessment locations. Combinations were based upon errors of commission (i.e. cover types that were inclusive within another class), our knowledge of caribou–habitat relations (Johnson, 2000), and the observed ecological similarities between the 27 identified cover types. Where possible, we attempted to maintain the singularity of those cover types with known relevance to caribou biology (e.g. pine–lichen).

Our composite image consisted of 17 cover types which, for purposes of multivariate resource selection analyses, we later compressed to 12 types. That number of ecological associations was considerably less

than the 72 vegetative classes of various serial stages that McKenzie (1993) documented using air photos at a scale of 1:70,000. Many of those classes, however, would need to be amalgamated before performing a statistically tractable analysis of habitat selection. We improved upon ecological maps that could be constructed with forest inventory data. For example, our final classification discriminated three alpine, two wetland, and krummholz cover types, none of which are considered during forest inventories. Subsequent analyses revealed that, depending on the scale of movement, caribou differentially selected among alpine cover types (Johnson et al., 2002). Creating a composite image of the original 27 cover types sacrificed some detail likely with relevance to understanding the movements and ecology of caribou. Of note, poor accuracy values forced us to combine black spruce with the larger pine–black spruce class; previous studies suggested selection by caribou for the black spruce cover type (Terry and Wood, 1999).

Caribou feeding sites and animal relocations collected with global positioning system (GPS) collars corresponded with several cover types. Fig. 2 illustrates differences in percent occurrence of cover types for small-scale movements of caribou and corresponding random sites. As reported for our site investigations and multivariable resource selection analyses, the difference between used and random sites infers selection by caribou for pine–lichen and alpine–rock (Johnson et al., 2001, 2002). The accuracy assessment suggests that pine–lichen has a spectral signature distinctive from the other pine dominated cover types such as the wetter more productive pine class and the mixed pine–black spruce stands. The technique presented here offers a low-cost means of mapping pine–lichen, an important forested cover type for populations of northern woodland caribou in BC. There also may be application to other *Rangifer* sub-species found in boreal and sub-boreal forests (e.g. Arseneault et al., 1997).

Mapping a large unroaded wilderness area, such as the one we studied, may appear daunting and prohibitively expensive. Our approach to mapping the 5100 km² Wolverine study area was relatively cost effective and efficient. We employed a fixed-wing aircraft for 4.5 h, a rotary winged aircraft for 6 h, collection of field data entailed 15 days for two field staff, and the classification procedure for one operator

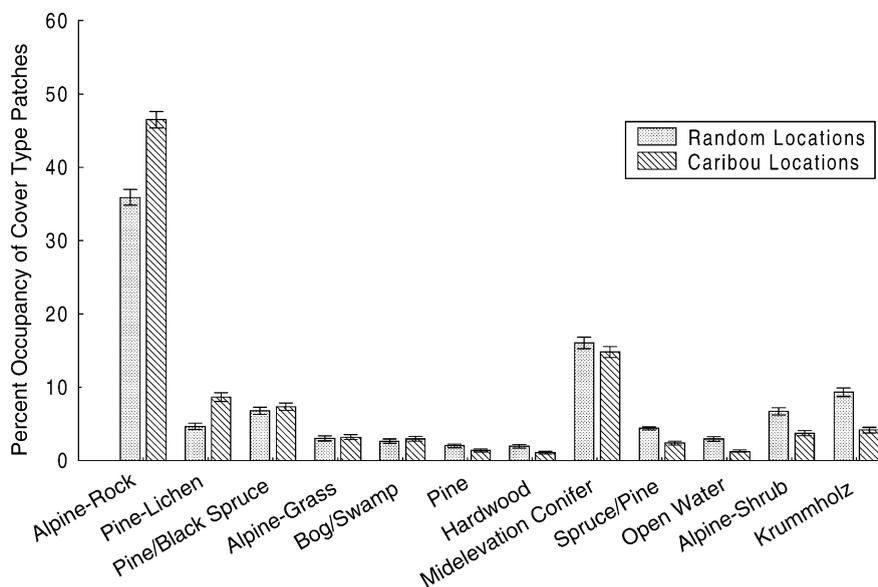


Fig. 2. Percent occurrence of aggregate cover types during small-scale movements of caribou ($n = 6935$) and corresponding random sites ($n = 6935$; error bars represent 95% confidence intervals). Location data were collected from 1996 to 1999 during the winter (1 December to 31 March) for 16 woodland caribou of the Wolverine herd in northcentral BC, Canada (Johnson et al., 2002).

was approximately 6 weeks. By far, the most expensive component of a project such as this is the collection of ground-truth sites to train the supervised classification and the acquisition of additional samples to assess the final classified image. We did, however, achieve considerable cost savings through the use of existing-field data. We used the data and classification scheme from a previous mapping project (McKenzie, 1993), site investigation data from related research (Johnson, 2000), and publicly available data of roads/trails, lakes, rivers, topography (government), and forest harvesting boundaries (industry). Similar ancillary data likely exists for at least portions of other project areas where existing or reliable maps are unavailable. We encourage researchers to search out and take advantage of those low-cost data sources.

Completion of this project and corresponding accuracy assessment allowed us to control the development and evaluate the vegetation maps to which we ascribed considerable importance in interpreting caribou movements and habitat affinities (Johnson, 2000). Evaluation and control were important considerations that weighed heavily in our decisions to pursue this project. Existing mapping products often claim adherence to predefined standards, but compliance is difficult to

establish and violation of those standards may have implications for interpretation (Stoms, 1992; Cherrill and McClean, 1995).

4. Conclusions

Our results suggest that Landsat TM imagery, in combination with topographic and other ancillary data, can be used to map boreal and sub-boreal ecological types. The technique and data were successful at identifying vegetation associations important as caribou habitat. Although our method is of a lower resolution than other techniques such as TEM, it is relatively inexpensive and will meet the needs of large-scale studies of caribou–habitat relationships.

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