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The effects of human land use on the winter habitat of the recovering Carcross woodland caribou herd in suburban Yukon Territory, Canada

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Abstract: Carcross woodland caribou (*Rangifer tarandus caribou*) numbers are increasing as a result of an intensive management and recovery program initiated in 1993. In the last 13 years, three overlapping First Nation land claim agreements were settled resulting in a complicated array of private and public land management authorities on this winter range, situated in the Whitehorse periphery. Twelve years of VHF radio-collar data (1994-2005) and 5 years of GPS radio-collar data (2000-2005) for female caribou were assessed to determine winter concentration areas and important winter habitats. We contrasted locations from 11 GPS radio-collared caribou with land cover classes, derived from classified Landsat 7 imagery, to evaluate the distribution and abundance of preferred habitats within this winter range. We found significant use of Open Needle Leaf lichen vegetation classes and avoidance of the relatively more abundant Closed Needle Leaf class. Our resource selection function model validated the preference for Open Needle Leaf Lichen and determined that caribou were spaced significantly further from an estimate of the human Zone of Influence (ZOI) than was expected from random locations. While our assessment determined that 64% of the winter range was located outside of either private lands or land influenced by human activity, key winter vegetation classes were under-represented within this area. If caribou are to successfully recover on this landscape and persist through time it is essential to manage, through meaningful participation among land management authorities, the remaining caribou habitat for environmental rather than human consumptive values.

Key words: Landsat imagery, northern mountain population, RSF model, radio-collars, zone of influence.

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Introduction

Caribou (*Rangifer tarandus caribou*) from the Carcross herd, and the people that rely on them, have persisted for centuries on the landscape of what is now the southwest Yukon Territory, Canada (Yukon). Cryo-preserved caribou dung and associated hunting artifacts date to 8330 years bp (Farnell *et al*., 2004; Hare *et al*., 2004). Market hunting associated with the Klondike gold rush, White Pass rail line and early riverboat travel (McCandless, 1985) was likely an important source of mortality to the Carcross and possibly other Yukon caribou herds. McCandless (1977) suggested the gold rush had a "crippling effect" on game and their habitat and that the RCMP were unable to prevent widespread slaughter. Resident meat hunting and non-resident sport hunting popular through the early 1920s (McCandless, 1985) likely kept numbers from increasing. Finally, construction of the Alaska Highway through the Carcross herd winter range in 1942 brought thousands of soldiers followed by an influx of new residents to the area. Even a modest harvest on this range likely maintained low caribou numbers through the latter half of the 20th century.

Since 1993 the Southern Lakes Caribou Recovery Program, a partnership between First Nations, non-government organizations, communities, and governments, has worked to increase two herds (Carcross and Ibex) to a common recovery objective of 2000 animals (Egli *et al.*, 2000) likely achievable within a few years. From 1994 to 2003, the Carcross herd increased from an estimated 300 to 850 animals (O'Donoghue, 1996; Farnell *et al.*, 1998; Yukon Government, unpublished data) and is expected to constitute 1400 of the 2000 caribou objective. Caribou from the adjacent Ibex herd make up the balance of the final recovery objective. Given the national trend of declining woodland caribou herds (Thomas & Gray, 2002) growth of these herds is noteworthy and could only have been achieved through a collaborative effort among recovery partners and the cessation of all hunting The recovery focus for the Ibex range is management of harvest and recreational activity on their sub-alpine winter range (Powell, 2004). Prior to and throughout the recovery period, the Carcross winter range has experienced increasing levels of linear development and landscape change associated with timber harvest, residential growth and industrial development in addition to increasing recreational use.

Carcross caribou habitually winter in close proximity to the heavily populated Southern Lakes area presenting a management challenge uncommon to most Yukon caribou herds and many other herds in the Northern Mountain Population (NMP; Thomas & Gray, 2002). The area is also home to 80% of the territory's 30 000 human residents, primarily in the Yukon's capital of Whitehorse, but also in five outlying communities. Yukon Government land policies evaluate disposition of public lands for residential and industrial use on a case by case basis (Yukon Government, 2006). In recent years applications for rural land have dramatically increased (Yukon Government, unpublished data) due to an apparent shortage of readily available residential building lots, agricultural properties and the attractiveness of a rural lifestyle. Much of this activity has been directed to the Whitehorse periphery and frequently to the winter range of the Carcross caribou. While the physical extent of each successive land disposition, timber harvest or land use activity may be small relative to existing dispositions, they should be evaluated in the context of cumulative habitat loss and/or displacement of caribou from important winter habitats.

Yukon woodland caribou are of the mountain terrestrial ecotype (Edmonds, 1991) and most of the 22 herds concentrate onto lichen dominated forested winter ranges (Farnell *et al.*, 1998). For the Carcross herd, terrestrial lichens constituted 76% of the estimated winter diet based on fecal fragment analysis from pellets collected between 1994 and 1997 (Yukon Government, unpublished data) and is consistent with other Yukon herds (Farnell & McDonald, 1989; Farnell & McDonald, 1990; Farnell *et al.*, 1991, Yukon Government, unpublished data). In southern Yukon, caribou winter in conifer forest types with low or poor quality soils, often glacial in origin, characterized by open forest canopies (25-50% crown closure) and well established lichen groundcover (Frid, 1998, Florkiewicz *et al.*, 2003). Similar relationships have been noted for woodland caribou in other jurisdictions (Cichowski & Banner, 1993, Wood, 1996). Caribou are frequently associated with mature and old forest cover types because of their reliance on slow growing lichen. Forest stands over 80 years of age were found to support terrestrial lichen cover (Thomas *et al.*, 1996; Szkorupa, 2002; Szkorupa & Schmiegelow, 2003); however, older stands are considered to be more productive. In some cases lichen can remain productive in pine stands up to 300 years old (Brulisauer *et al.*, 1996).

Integrity of winter range is fundamental to ensure both the availability of lichen and the ability of caribou to access it. How winter range integrity is maintained has become the subject of considerable research and management effort in the last decade, largely around the threatened Boreal (BP) and Southern Mountain Populations (SMP) (Thomas & Gray, 2002; McLoughlin *et al.*, 2003). Forest and wildlife managers are increasingly concerned as caribou numbers have declined in the face of significant landscape changes. These are associated with timber harvest (Smith *et al.*, 2000; Mahoney & Virgil, 2003; Morgantini & Schmiegelow, 2004; Saher & Schmiegelow, 2005) and the proliferation of linear corridors usually associated with the oil and gas and forest industries (James, 1999, James & Stuart-Smith, 2000; Dyer *et al.*, 2001). The mechanisms for change in caribou numbers, recently reviewed by Adamczewski *et al.* (2003), include factors that influence caribou directly such as habitat loss, increased road kill, and illegal harvest, and indirectly such as displacement into poorer habitats, increased prey biomass supporting higher predator populations, and increased predator efficiency. In their review of human factors contributing to the declining trend in other caribou populations, Thomas & Gray (2002) reasoned that many of these were also influencing NMP caribou and therefore a recent status assessment elevated this population to "Special Concern" (COSEWIC, 2002).

Winter ranges are considered "key areas" within the Yukon Wildlife Key Area inventory program. This designation indicates part of a species range considered essential to its life function (Yukon Government, 2005). This program serves to provide an early alert to potential wildlife issues where land development is being considered. However, for the Carcross winter range, land management decisions are being made at a much finer scale than the winter range, frequently measured in 10s of hectares. In addition, neither the

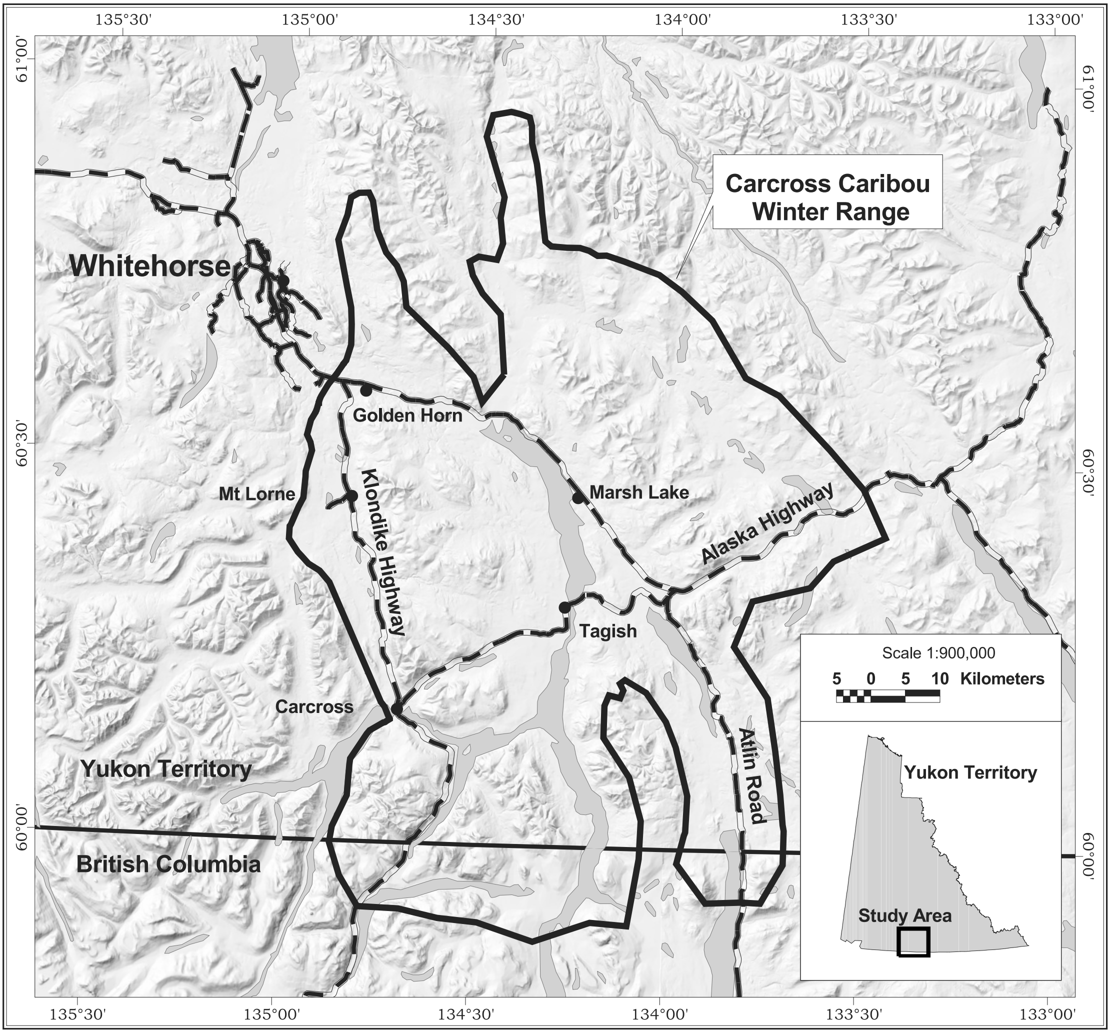

Fig. 1. Location of Whitehorse, outlying communities and major highway corridors relative to the Carcross caribou winter range.

key area program nor designation as a winter range advise sufficiently well on land use practices as they cover large areas and include substantial proportions of what could be considered non-habitat for wintering caribou.

To further our understanding of the Carcross caribou herd, of challenges to achieving the recovery objective for this herd on this landscape, and our ability to advise land use processes, we evaluated 12 years of data from radio-collared caribou using a satellite based land cover classification and a detailed assessment of human land use on this range. Our specific objectives were:

1: To empirically assess winter range and to define a core winter range based on radio-collared caribou and habitat values within them; and,
2: To evaluate the relative influence of human activity on winter habitat important to this herd.

This assessment can then be used to support decision making on the disposition and/or retention of land in the Whitehorse periphery. If the Carcross herd is to persist, it is essential to develop a management program based on a clear understanding of how caribou use the landscape and the potential risks from existing and future development.

Study area

The Carcross caribou winter range is located in south-central Yukon and straddles the Yukon-British Columbia border (Fig. 1). The area lies within the Southern Lakes Ecoregion (Yukon Ecoregions Working Group, 2004) which is characterized by large lakes, broad valleys and a number of mountain peaks over 2000 m asl. It is strongly influenced by the most recent (McConnell) glaciation and fluvial processes associated with water impounded behind retreating glaciers. The landscape is dominated by glacio-fluvial gravels overlain with lacustrine clays and silts. Soils are predominantly Eutric Brunisols overlying a variety of glacial parent materials, some of which are influenced by scattered discontinuous permafrost. The area is within the heart of the Coast Mountain rain shadow where precipitation varies between 200 and 325 mm annually, one third to one half as rain. Snow depth, measured at the Whitehorse airport, at the end of March averaged 31 cm, (Environment Canada; http://www.climate.weatheroffice.ec.gc.ca/climate-normals). Annual mean temperatures range between -1 °C and -2 °C. Forests are largely open coniferous and mixedwood, dominated by pine (*Pinus contorta*) or mixed pine/spruce (*Picea* spp.) on glaciofluvial and morainal deposits. White spruce forest stands are scattered in lowland habitats and shrub birch (*Betula glandulosa*) dominated stands underlain by lichen and forbs occur at higher elevations.

Material and methods

Animal capture and monitoring

From 1994 to 2005, 30 very high frequency (VHF) radio-collars (Telonics Inc., Mesa, AZ, USA) were placed on adult female caribou on the Carcross caribou range. Between 1999 and 2004, 11 adult female caribou were fitted with Global Positioning System (GPS) radio-collars (Lotek Engineering, Newmarket, ON, Canada; Models GPS_2200 & GPS_3300). All animals were captured using aerial net gun techniques (Barrett *et al*., 1982). VHF radio-collar locations were gathered seasonally using fixed and rotary wing aircraft, at least five times per year to coincide with calving and post-calving, rut, early and late winter periods. We used individual GPS radio-collared caribou positions as VHF locations when they were located on routine telemetry flights. GPS radio-collars were programmed to gather locations at intervals ranging from one to six hours. Locations with dilution of precision (DOP) values greater than 8 were removed from the sample (British Columbia Standards, 2001). For the purposes of this study, the winter period was considered to be November 15 through April 15.

Characterization of winter range

A generalized winter range boundary (Fig. 1), established as part of the management initiative for the Carcross caribou herd (O'Donoghue, 1996; Smith & McDonald 1996) was revised in 2003. The revision included new information for caribou range use (from local observations and updated survey information) and on habitats near the range periphery considered valuable caribou habitat. To refine the winter range configuration and to identify concentration areas within the winter range, we generated home range estimates by the adaptive kernel method (Worton, 1989; Worton, 1995). We used the Animal Movement Extension (Hooge & Eichenlaub, 1997) for ArcView 3.3 (ESRI, 2002), with least-squares cross-validation to estimate the smoothing parameter, on VHF caribou locations between 1994 and 2005. This method takes advantage of the large number and relative density of caribou locations in generating concentration areas within the winter range with a limited bias (Seaman & Powell, 1996). This contributes added rigour over "expert opinion" approaches to mapping animal range. We objectively identified a core area using a utilization plot (Kenward, 2001). Range area estimates were calculated at 5% increments from the 20% to 95% isopleths. Range area generally increases linearly with increasing isopleth level. Range area was plotted against isopleth level and a core area (isopleth) identified at the first discontinuity in this linearly increasing trend. Caribou locations were entered as either Garmin GPS waypoints (WGS 84 datum) or, for earlier surveys, were digitized from locations recorded on 1:250 000 scale topographic maps.

A Landsat 7-derived land cover classification of the Southern Lakes Region (Ducks Unlimited *et al*., 2002) was used to describe caribou winter range. Analysis of this classification was done using PCI Geomatica v. 9.1.5 (PCI, 2004). A 3x3 mode filter was applied to the classification to remove "noise" associated with isolated pixels. Spatial/statistical overlays were performed on the filtered classification with coverages representing human land use, land ownership, and winter locations of GPS-collared caribou (see Bechtel *et al*., 2004). Overlays were performed for the generalized winter range and subsequently contrasted with the kernel home range estimates. Vegetative characteristics from aerial plot data gathered through the initial Landsat mapping initiative (Ducks Unlimited *et al*., 2002) were summarized to evaluate important lichen supporting classes.

Human use on the landscape was established through comprehensive mapping of all discernable land uses within the generalized winter range boundary (Applied Ecosystem Management, 2004). Each feature identified from digital topographic data (Natural Resources Canada, 2003), digital orthophotos, and cadastral layers was classified by land use type and mapped as a polygon layer within ArcGIS (ESRI, 2005). To approximate the influence of human activity within human use areas, we applied a buffered polygon around each feature to represent a "Zone of Influence" (ZOI). Values for the extent of the ZOI were derived from existing literature where appropriate, from the UNEP (2001) Globio standards, or were otherwise developed by a

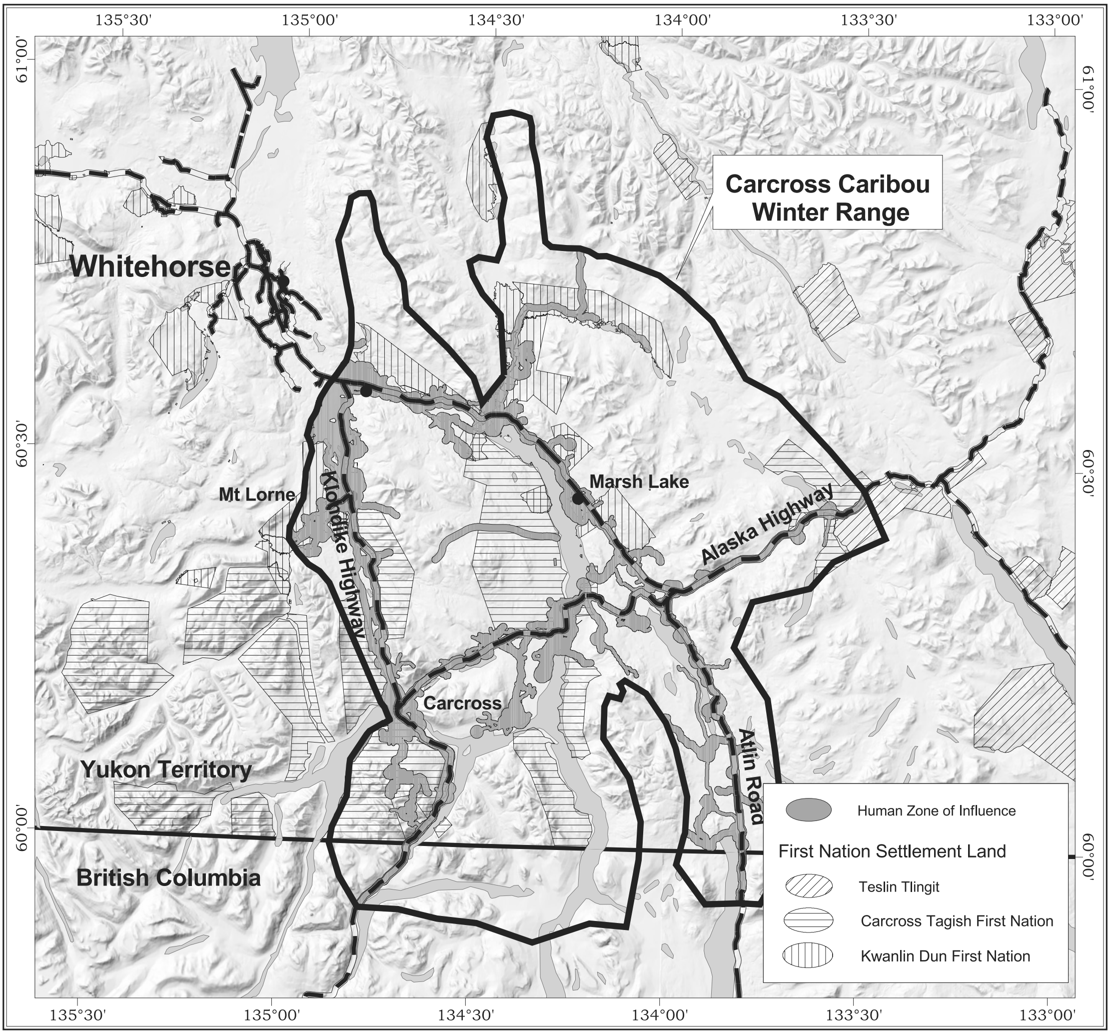

Fig. 2. Distribution of First Nation land selections, private land and estimated human Zone of Influence (ZOI) around development in the Carcross caribou winter range.

group of local experts (Applied Ecosystem Management, 2004; Appendix 1).

Caribou winter range influenced by land use was evaluated by intersecting the human land use (ZOI) coverage with the Landsat derived classes. We also included First Nation land selections as human land use within the winter range (Fig. 2) as they are not within the "public" domain for possible development. We assume, in the short term, that First Nation partners will direct development on settlement land away from important winter habitats.

We assessed type I, or first order selection (Johnson, 1980) by GPS radio-collared caribou over the entire landscape. Using Bonferonni confidence intervals (Neu *et al*., 1974), we evaluated the relative frequency of caribou use for each land cover class (Ducks Unlimited *et al*., 2002) (see Bechtel *et al*., 2004).

Human Impact on Caribou Winter Habitat

To assess the impact of the human footprint on caribou winter habitat we developed a resource selection function (RSF; Manly *et al*., 2002). RSFs are statistical models that calculate values proportional to the actual probability of use of resource units on the landscape (Manly *et al*., 2002; Johnson *et al*., 2006). This provides a framework to assess and quantify the impact of certain landscape changes, such as human infrastructure, on habitat (e.g., Johnson *et al*., 2005). We modelled third-order selection patterns (Johnson, 1980) of adult female caribou during winter following a use - availability sampling protocol (Manly *et al*., 2002) whereby a sample of locations used by GPS radio-collared caribou was compared to a random sample of points on the available landscape. We adopted a design 4 strategy (Thomas & Taylor,

2006) in which used locations were paired with available locations for the analysis.

The full relocation dataset consisted of 20 833 relocations from 11 individuals. To reduce autocorrelation in the relocations (Nielsen *et al.*, 2002) and to create a balanced sample of used points among individuals, we randomly selected 325 locations for each individual for inclusion in the analysis. Around each of these used locations we generated a buffer (Johnson *et al.*, 2005) of radius 1.1 km which was equal to the median daily distance moved by the GPS radio-collared caribou. Within each buffer, five random points were generated to represent availability using Hawth's Tools (Beyer, 2004) for ArcGIS 9.1 (ESRI, 2005). Five random points were chosen because the addition of more available points would not provide any additional information (King & Zeng, 2001).

To generate the RSF we modelled the binary response variable (used vs. available) with eight spatially explicit covariates mapped within a GIS (ArcGIS 9.1; ESRI, 2005). All covariates were mapped at a 30-meter pixel resolution. Covariates were selected based on previous research and our observations of caribou behaviour during winter in the study area. We collapsed the existing landcover map (Ducks Unlimited *et al.*, 2002) from 31 classes to 12 to increase parameter certainty. Original cover types were grouped into what we felt were biologically meaningful functional classes. Each new cover class was treated as a binary indicator variable. Elevation (meters) was calculated from an existing digital elevation model (DEM) of the study area. Slope (degrees), aspect, and hillshade were derived from the DEM using Spatial Analyst for ArcGIS 9.1 (ESRI, 2005). Aspect was classified into five classes based on the cardinal direction (east, west, north, or south) of the pixel or flat (reference category) if the slope of the pixel was less then five degrees. The Euclidean distance (meters) to the nearest water body was calculated in ArcGIS 9.1 using an existing hydrographic database. A topographic position index (TPI; Jenness, 2005) was calculated using the DEM and a 300-meter circular window and provides an indication of slope position. Negative TPI values indicate valley bottoms while positive values indicate ridge or hill tops. Values near zero indicate flat areas. The final predictor, human zone of influence (ZOI), represents the area on the landscape affected by human infrastructure (Applied Ecosystem Management, 2004). We rasterized the initial vector-based ZOI to a 30-meter pixel resolution, providing a binary variable indicating whether the location was in or out of the ZOI. The value, or category, of each covariate was extracted for all used and available locations. We assessed for collinearity by calculating the Pearson correlation between variables and used $|r| > 0.6$ as the threshold for removing one of the covariates.

We used conditional fixed-effects logistic regression (Long & Freese, 2003) to estimate the model coefficients. Analyses were carried out in Stata/SE 9.2 (StataCorp, 2005). We followed an information-theoretic approach (e.g., AIC) for identifying the most parsimonious model (Burnham & Anderson, 2002). This model was determined using a forward-looking stepwise-AIC (SWAIC) approach (Nielsen *et al.*, 2003), in which covariates were added to the model until parsimony was reached. To account for possible lack of independence of locations from the same individual we used a modified sandwich estimator to calculate robust standard errors (Nielsen *et al.*, 2002). To assess the model's predictive ability we used a *k*-fold cross-validation procedure (Boyce *et al.*, 2002) to calculate a Spearman rank correlation coefficient (r_s).

From the final selected model we applied the RSF to the landscape to generate a relative distribution map of caribou occurrence. We used the quantile function in ArcGIS 9.1 to classify the map into ten quantiles. This map represented the habitat effectiveness of the current winter range. Habitat effectiveness is an estimate of the percentage of habitat available to caribou after subtracting habitat alienated by human influences. We reapplied the RSF to the landscape removing the ZOI from the landscape (i.e., no human influence in the study area). Again we classified the map into ten quantiles representing the habitat potential of the study area. Habitat potential theoretically reflects the inherent ability of the landscape to support caribou without human activity. Thus, pixels in both maps were classified from one through ten, where one indicated low habitat quality and ten represented the highest habitat quality. To both quantify, and visualize, the reduction in habitat quality due to the influence of human activity we subtracted the habitat effectiveness map from the habitat potential map in the GIS. We then generated a difference map indicating the difference between the habitat potential and effectiveness maps. The possible minimum and maximum differences between the two maps were zero and nine, respectively. To quantify habitat quality reduction we calculated the proportion of this difference map that was made up of each of the ten possible values. High difference values indicate relatively large reductions in habitat quality whereas small or no differences indicate a negligible loss.

Results

Winter range and core area

We generated an adaptive kernel winter range estimate based on 434 winter VHF locations (November 15-April15) from the total sample of 741 locations over all seasons and years. Estimates of winter range

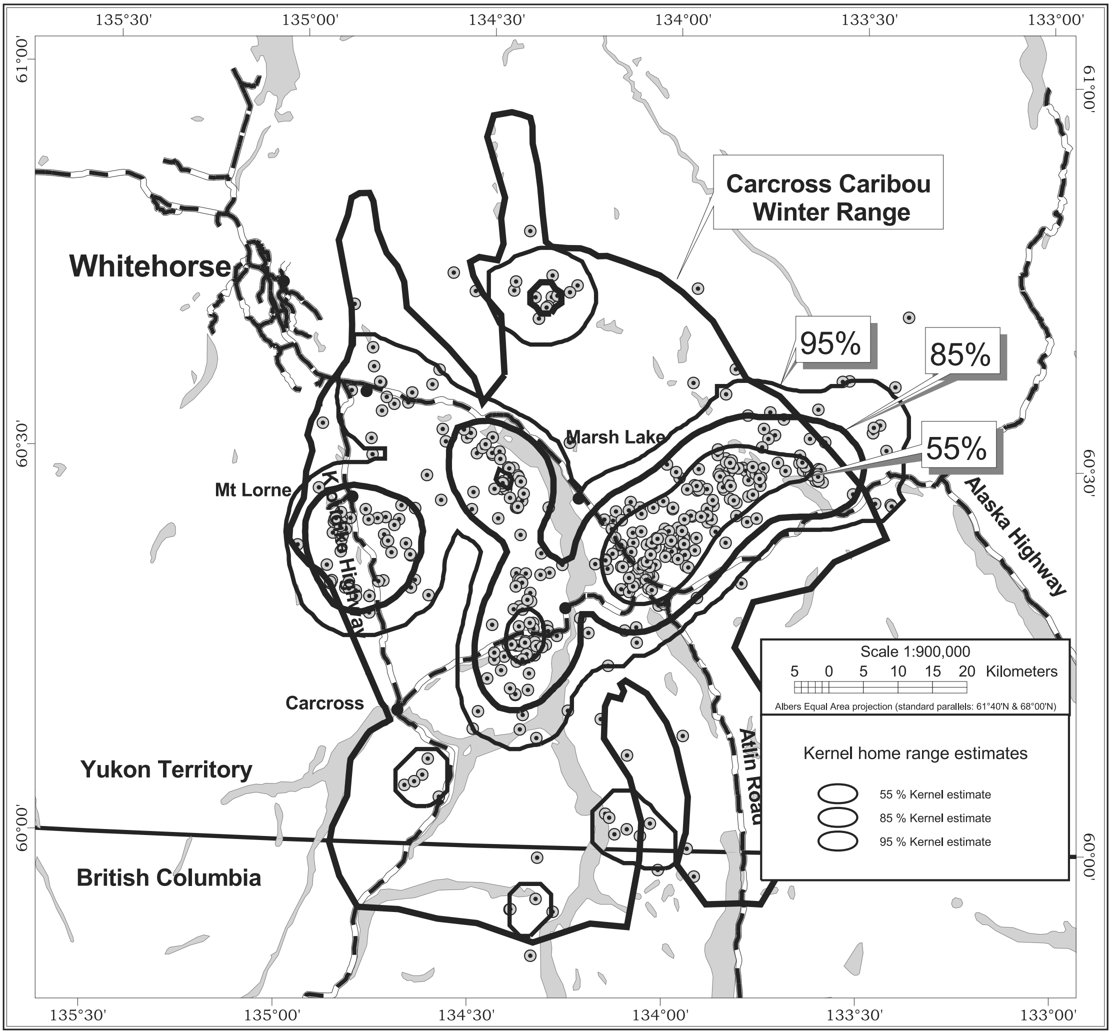

Fig. 3. Kernel home range estimate for 41 radio collared caribou in the Carcross caribou winter range.

represented 6.3%, 26.8% and 53% of the Carcross winter range area for the 55%, 85% and 95% kernel isopleths respectively (Fig. 3; Applied Ecosystem Management Ltd., 2004). The utilization plot indicated a core area at the 85% isopleth.

Habitat assessment

Vegetation characteristics for 401 aerial sample plots gathered through the satellite land cover classification were summarized into principle forage categories for each of the 25 land cover types identified (Table 1). Of these, 11 forested classes represented 73.6%, and 8 shrub classes an additional 15.3% of the winter range. The remaining area was dominated by water (6.2%), sparsely vegetated, rock-gravel, lichen or forb classes. With the exception of the Closed Needleleaf (CN) and Open Pine (OP) classes, no cover type contributed more than 10% to the total winter land cover (Table 2). Only the Open Needleleaf Lichen (ONLi; 33.5% lichen cover) and Woodland Other (WOt; 17.9% lichen cover) classes supported substantial lichen cover. The WOt class is an open canopy class of conifer-dominated forest type of which 5 of the 9 plots sampled were classified as Woodland Needleleaf/Lichen. Shrub lichen classes were associated with subalpine parts of the range.

Habitat availability

The influence of human activity through direct loss of habitat, including private, public, and recreational features (Table 3) was estimated to be 3.3% of the winter range (Applied Ecosystem Management, 2004). The estimated indirect influence or ZOI after applying the buffers to these features (Appendix 1) increased the estimate of human influence to 16.7% of the winter range (Fig. 2).

Table 1. Vegetation characteristics for 25 land cover classes found in the Carcross caribou winter range as outlined in Fig. 1.

				Mean % Cover							
Cover Type	ID	Symbol	Plots	Tree	Shrub	Forb	Graminoid	Lichen	Moss/Fern	Litter	Other[1]
Closed Needleleaf	1	CN	28	65.2	15.9	2.7	0.5	1.6	5.5	7.0	1.6
Open Mixed Needleleaf	2	OXN	6	43.3	19.2	6.7	1.7	2.5	10.0	15.0	1.7
Open Needleleaf Lichen	3	ONLi	10	34.5	12.5	0.5	0.0	33.5	1.0	14.0	4.0
Open Spruce	4	OS	24	34.8	35.0	3.1	0.4	7.9	7.7	7.5	3.5
Open Pine	5	OP	25	41.6	19.8	4.8	0.6	7.0	1.8	22.6	1.8
Closed Mixed Needleleaf Deciduous	6	CXND	1	70.0	5.0	5.0	0.0	0.0	10.0	10.0	0.0
Open Mixed Needleleaf Deciduous	7	OXND	12	39.2	32.9	6.3	3.3	0.8	0.4	15.8	1.3
Woodland Shrub	8	WSh	28	14.5	51.8	3.8	3.2	6.1	8.0	10.4	2.3
Woodland Other	9	WOt	9	17.2	27.2	2.8	5.6	17.8	4.4	12.8	11.7
Closed Deciduous	10	CD	10	68.5	14.0	9.5	2.5	0.0	0.5	4.5	0.5
Open Deciduous	11	OD	16	44.4	30.6	8.4	4.4	0.3	0.0	7.5	4.4
Tall Shrub	12	OCTSh	28	2.5	62.9	7.0	9.5	2.1	2.5	9.6	3.0
Closed Low Shrub	13	CLSh	19	1.1	76.8	2.1	4.2	8.4	2.9	3.2	1.3
Open Low Shrub	14	OLSh	28	1.4	62.3	5.7	8.4	5.9	2.0	8.0	6.1
Open Low Shrub Herb	15	OLShHb	15	2.0	46.7	9.3	25.3	2.7	2.7	7.7	2.7
Open Low Shrub Lichen	16	OLShLi	12	0.8	50.4	2.5	5.0	26.7	1.7	3.3	9.6
Dwarf Shrub Other	17	DsOt	28	0.7	40.9	16.8	7.9	8.0	1.8	5.7	17.9
Dwarf Shrub Lichen	18	DsLi	27	0.4	33.1	20.0	6.7	24.1	0.4	2.4	13.0
Dwarf Shrub Herb	19	DsHb	14	0.7	22.5	20.0	23.6	11.4	0.7	9.3	10.7
Mesic Dry Forb	20	MYFb	2	2.5	10.0	25.0	10.0	0.0	10.0	17.5	25.0
Lichen	21	Li	2	0.0	5.0	17.5	22.5	32.5	0.0	10.0	12.5
Clear Water	24	Wc	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0
Rock – Gravel	27	Rg	28	0.0	1.3	2.0	0.2	0.8	0.4	0.4	95.0
Sparse Vegetation	28	Sv	15	0.3	7.3	9.0	4.3	4.7	3.0	3.3	68.0
No data[2]	32	Ot	10	1.0	4.5	13.0	24.5	0.0	2.0	4.5	9.0

[1] Other composition category is the combined classes including Algae, Bare ground, Snag and Snow.
[2] No data Type given to plots that did not fall into any other class (Ducks Unlimited *et al.*, 2002).

Table 2. Distribution (area and %) of land cover classes (Ducks Unlimited, 2002) over the Carcross caribou herd winter range, within the human Zone Of Influence, and the 85% Adaptive Kernel.

	Total winter range		Human ZOI		85% Adaptive kernel	
Landcover class	Area (ha)	Proportion of total (%)	Area (ha)	Proportion of human ZOI (%)	Area (ha)	Proportion of total (%)
CN	134205	24.2	15309	16.5	36326	24.6
OXN	16992	3.1	3523	3.8	5331	3.6
ONLi	25073	4.5	8764	9.5	12481	8.4
OS	54291	9.8	10969	11.9	15069	10.2
OP	59468	10.7	13661	14.8	19816	13.4
CXND	9920	1.8	372	0.4	1893	1.3
OXND	33652	6.1	4780	5.2	8595	5.8
WSh	7946	1.4	1020	1.1	1412	1.0
WOt	8767	1.6	1977	2.1	1462	1.0
CD	51995	9.4	7789	8.4	15494	10.5
OD	5473	1.0	1296	1.4	1470	1.0
OCTSh	11879	2.1	1127	1.2	2470	1.7
CLSh	19775	3.6	1577	1.7	3896	2.6
OLSh	16853	3.0	1192	1.3	2818	1.9
OLShHb	7236	1.3	763	0.8	1354	0.9
OLShLi	12978	2.3	2203	2.4	2749	1.9
DsOt	9205	1.7	1052	1.1	1078	0.7
DsLi	5388	1.0	891	1.0	265	0.2
DsHb	1551	0.3	281	0.3	77	0.1
MYFb	560	0.1	71	0.1	73	< 0.1
Li	754	0.1	43	0.1	32	< 0.1
Wc	34199	6.2	5869	6.3	8900	6.0
Rg	2818	0.5	257	0.3	98	0.1
Sv	9391	1.7	1255	1.4	661	0.4
Other	15071	2.7	6551	7.1	4030	2.7
Total	555448	100	92594	100	147851	100

Table 3. Contribution of anthropogenic feature classes to the total human footprint within the Carcross caribou winter range.

Feature Class Description	Contribution of each feature class to total human footprint: Area (ha)		% study area	
	Direct[1]	Indirect[2]	Direct	Indirect
Agricultural	2811.5	3439.7	0.48	0.59
Industrial	1438.4	7759.3	0.25	1.33
Recreation	8177.0	19800.6	1.40	3.39
Transportation	4646.6	43628.5	0.79	7.46
Urban	2343.0	22763.2	0.40	3.89
Total	97391.2	19416.5	3.3	16.7

[1] Direct pertains to the actual area covered by a land disposition.

[2] Indirect pertains to an area beneath the Zone of Influence buffers applied to each feature class.

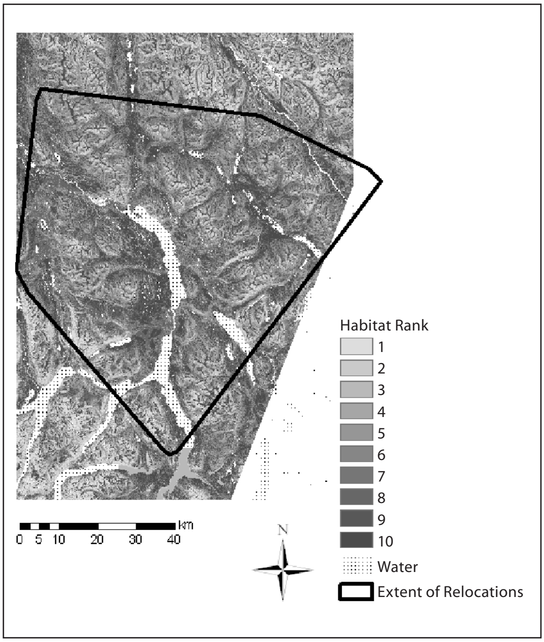

Fig. 4a. Current habitat ranking of caribou winter habitat in the Southern Lakes region of the Yukon Territory, Canada. The solid line is a 100% minimum convex polygon of all winter GPS relocations collected during the study.

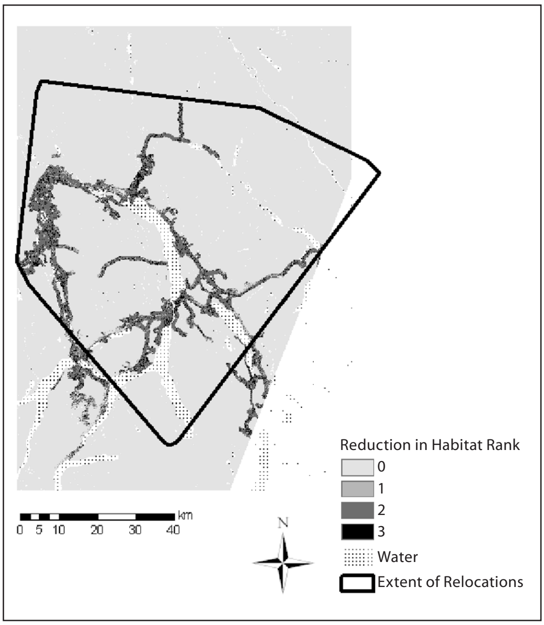

Fig. 4b. Reduction in winter caribou habitat ranking when the ZOI was included on the landscape in the Southern Lakes region of the Yukon Territory, Canada. The solid line is a 100% minimum convex polygon of all winter GPS relocations collected during the study

Within this same winter range, three First Nations have land interests through settlement of individual Land Claim Agreements. Collectively, First Nation controlled lands cover 24.4% of the Carcross caribou winter range. While collaboration in the Southern Lakes Caribou recovery plan can facilitate joint management of winter range under First Nation jurisdiction, it is important to recognize they are privately held lands. Consequently, private holdings, the ZOI around those holdings and First Nation held lands

Table 4. Proportional distribution of land cover classes remaining within the total Carcross caribou herd winter range (555 448 ha) but outside of the Zone Of Influence and of First Nation settlement land combined (64.6% of winter range).

	Outside of settlement land and outside of ZOI	
Land cover class	Area (%)	Proportion of total land cover class remaining (%)
CN	25.4	68.0
OXN	2.5	53.7
ONLi	2.4	34.3
OS	8.2	54.2
OP	8.5	51.1
CXND	2.3	82.5
OXND	6.5	69.4
WSh	1.5	68.7
WOt	1.5	62.6
CD	9.7	67.1
OD	0.8	53.7
OCTSh	2.6	77.9
CLSh	4.5	81.2
OLSh	3.8	80.5
OLShHb	1.5	72.9
OLShLi	2.5	68.6
DsOt	1.9	75.6
DsLi	1.1	71.0
DsHb	0.3	69.5
MYFb	0.1	77.5
Li	0.2	84.2
Wc	7.7	81.0
Rg	0.6	72.1
Sv	1.7	64.3
Other	2.3	
Total	100	64.6

currently account for 35.4% or just over a third of the winter range.

Cover types were not uniformly represented over the landscape. ONLi was substantially under represented as only 34% of this type is available within the unencumbered land base where proportional distribution would suggest values nearer 65% (Table 4). Other spruce and pine forest types, with the exception of CN are also somewhat lower than what would be proportional representation (51-54%). These patterns remained consistent when contrasted within the 85% kernel isopleth. Most vegetation types occurred in proportion to the entire winter range with the exception of ONLi and OP classes where these, similar to the ZOI assessment were over-represented suggesting concentration within a smaller proportion of the total winter range.

Habitat selection by GPS radio-collared caribou

Our assessment using Bonferonni confidence limits identified consistent selection for ONLi forest and DsOt shrub habitat types ($P<0.0001$, df =19) whereas use of CN forest cover types was significantly lower than would be predicted from availability ($P<0.0001$, df =19). Contrasts for other habitat types were not significant.

The final RSF model consisted of 25 317 points with 4220 used locations and 21 097 random locations. Five used locations from one individual and three random locations were censored from the dataset as they fell outside the coverage of our land cover classification. The most parsimonious model identified via the SWAIC procedure consisted of 14 coefficients (Table 5). The human infrastructure (HI) landcover category was dropped due to redundancy with the ZOI. The *k*-fold cross-validation procedure indicated the model was highly predictive (r_s = 0.96).

Table 5. Variables included in the most parsimonious model of adult female caribou winter habitat selection in the Southern Lakes region of the Yukon Territory, Canada.

Variable	Coefficient	Standard Error
TPI	0.02493	0.00675
Slope	-0.02213	0.00948
Hillshade	-0.00344	0.00228
Zone of influence	-0.43575	0.04807
Aspect – north	0.16895	0.13071
Aspect – east	0.05918	0.11410
Aspect - south	-0.05804	0.15910
Aspect - west	0.06037	0.13244
ONL	0.53678	0.14543
WNL	-1.00289	0.37499
CD	0.31652	0.07071
LSh	0.11203	0.12690
DSh	0.69814	0.22498
Non-vegetated	-1.11551	0.23307

An aggregate RSF (habitat) model generated by this analysis is presented in Fig. 4a. Probability of occurrence increased as the topographic position neared ridge or hilltops, and in open needleleaf, closed deciduous, low shrub, and dwarf shrub cover types. It decreased with increasing slope and hillshade, within the ZOI, and in woodland needleleaf and non-vegetated cover types. Relative to flat locations, occurrence was greater on north, east and west aspects, and lower on south aspects.

The reduction in habitat quality due to the ZOI (Fig. 4b) was estimated within a 100% MCP of all GPS relocations collected during the study. The MCP for this comparison is a close approximation of the Carcross caribou winter range in distribution and in overall area 53 4174 ha. Within this MCP, 9.2% of the area experienced a reduction in ranking when the ZOI was present. 1.3% was reduced by one rank, 6.1% reduced by two ranks, and 1.8% reduced by three ranks.

Discussion

Management of development activity on NMP caribou winter habitat embraces the concept of large undeveloped leave-areas (Smith *et al*., 2000; Morgantini & Crosina, 2004) while increasing the intensity of activity in industrial zones. This could be an effective strategy for some Yukon herds, for example Wolf Lake (Farnell & McDonald, 1989) or Little Rancheria (Florkiewicz *et al*., 2003), where caribou winter in relatively large and discrete areas. However, the Carcross range, bisected by large lake systems and mountain massifs, is arranged differently. Human activity through three Yukon highways, numerous private land dispositions and timber harvest areas are concentrated in forested valley bottoms also used by caribou. While the absolute area removed from the winter range through direct physical alienation appears relatively small, the projected influence characterized by the ZOI (Applied Ecosystem Management, 2004) demonstrates a much greater potential threat to caribou through avoidance of important wintering areas.

Salmo Consulting (2004) reviewed a substantial body of literature documenting both decline in southern caribou herds and avoidance of human development concurrent with increased human land use. Declines are often attributed to increased natural and human caused mortality (Seip, 1992; Harding & McCullum, 1994) and considered an example of cumulative effects of habitat loss, fragmentation and human development. Avoidance of human activity, considered an anti-predation strategy (Dyer, 1999; James and Stuart Smith, 2000) has also been documented for woodland caribou in west central Alberta (Oberg, 2001). Increasingly, the influence of human activity on caribou and other species are used to identify zones of reduced habitat value (Axys, 2001; Johnson & Boyce, 2001; Salmo Consulting, 2004; Johnson *et al.*, 2005) although the implications for caribou are difficult to demonstrate outside of theoretical models.

The disproportionate over-representation of two preferred habitat types (ONLi and OP) within our modelled ZOI and resultant under-representation in the remaining winter range is a concern. Similarly, significant avoidance of the ZOI by GPS radio-collared caribou suggests at least some influence on caribou from the existing footprint. Concentration of caribou into habitats outside of the ZOI would increase winter foraging pressure and potentially reduce lichen abundance in preferred habitat types. Increasing density of caribou on important winter feeding habitats may reduce the effectiveness of dispersion as an anti-predation strategy (Seip, 1992; James, 1999). Management of the remaining intact sections of winter range, particularly to avoid additional linear development and subsequent human activity is essential to maintaining Carcross caribou into the future.

Lichen producing habitats on the Carcross caribou winter range are dispersed, likely the result of the interaction between glacial deposition and post glacial hydrology in generating a complex assemblage of geologic land forms around the southern lakes. Classic glacio-fluvial origin pine stands (Cichowski, 1993; Florkiewicz *et al.*, 2003; Johnson *et al.*, 2004) are represented within the range although some areas have been modified by deposition and erosion events during periods of post glacial melt water release (Yukon Ecoregions Working Group, 2004). In conjunction with landform, low intensity ground fire is considered an important stand maintaining agent (Ahti & Hepburn, 1967; Applied Ecosystem Management, 1998; Goward, 2000) and possibly support long term persistence of postglacial caribou winter ranges on the landscape.

Lichen density within the Carcross range appears to be lower than in other ranges within the Yukon. Florkiewicz *et al.* (2003) identified mean lichen cover of 40% and ranging upwards to 95% on pine/lichen sites in some parts of the Little Rancheria caribou winter range. The depth and density of lichen mats also appeared greater than is generally noted for much of the Carcross winter range. Preferred lichen dominated habitats supported mean lichen cover ranging between 7% and 18% in Open Pine and 33.5% to 43% in Open Needleleaf Lichen types (Yukon Government, unpublished data). Overall, distribution of these habitats were widely dispersed over the landscape unlike the range of the Little Rancheria herd where much more entire and central to the wintering area (Florkiewicz *et al.,* 2003).

Core range use by caribou is often identified for caribou range (Schindler, 2004; Schmelzer *et al.*, 2004) and explicitly defined as the portion of a home range where use is high, exceeding an equal use pattern (Samuel *et al.,* 1985; Harris *et al.*, 1990; Kenward, 2001). Core areas may provide clearer measures of changing patterns of range use (Harris *et al.*, 1990). Based on the concept of exceeding equal use (Harris *et al.,* 1990) and discontinuity between successive kernel isopleths (Kenward, 2001), we suggest a core area at the 85% kernel for the Carcross caribou winter range. Although this represents only 27% of the winter range, the area supports 50% of the ONLi and 33% of the OP habitats preferred by GPS radio-collared caribou. Clearly, the concentration of both habitat and caribou into this area suggest it is critically important to the long term well being of this population.

Access to lichen may ultimately become a limiting factor for this herd. Parts of the lichen dominated historic range have largely excluded caribou (e.g., Cowley Creek and McClintock subdivisions) or are substantially altered as in the case of the Golden Horn subdivision and agricultural development to the east (UMA Engineering & Gartner Lee, 2004). It would be naive to consider that all activity within the area be halted. The demand for access to resources continues; a gas pipeline corridor has been proposed through the winter range since the 1970's along with the more immediate demand for domestic fuel wood, aggregate, and land for residential development (Nairn and Associates, 1993; UMA, 2004). Concurrently, off road vehicle (ORV) and snowmobile technology have greatly increased the human presence in all seasons (Hayes, 2000). Both humans and caribou have increased their use of the land over the recovery period for this herd. Settlement of three land claim agreements in the greater Whitehorse area have further complicated land management issues where part of the land base is excluded from consumptive public use that would otherwise meet some of the growth and development needs. Development is thereby concentrated onto the remaining land and managed by the Yukon Government. Co-operative management agreements on First Nation Settlement Land could, in future, satisfy some of the public demand for resources if caribou winter habitats are considered prior to development.

Regardless of the timescale, in resource development, the value of resource inventory and stewardship is to identify the most sensitive parameters and undertake management activities taking these into account. In most cases management is more likely to succeed if knowledge gained through assessments is used with full stakeholder participation, coordination in land management and planning and where government policy direction and leadership is strong (Morgantini & Schmiegelow, 2004).

Our study demonstrated that Carcross caribou select pine dominated vegetation types during winter and occupy relatively dispersed high density areas within a broad winter distribution. High value winter vegetation types are disproportionately over-represented within existing land use ZOI and private lands. This reflects the tendency for development in forested valley bottoms also home to wintering caribou. If development increases in high value vegetation types, either direct habitat loss or avoidance of areas associated with human influence will likely compress caribou into fewer remaining suitable sites. Concentration in this manner can increase their vulnerability to predation and increase the risks from fire or human caused (resource/residential/recreational) changes. Land planning and associated communication with land users will be essential to ensuring the successful recovery of the Carcross caribou on this suburban land base.

While the caribou concentration areas and important associated habitats were well represented through the 85% kernel home range polygon, areas of concentrated caribou winter vegetation and know concentration areas of caribou also occurred on the winter range outside of even the 95% kernel range limit. This can be remedied in future years as additional caribou are radio-collared. If the Carcross herd continues to grow, some used areas not represented through these data may become evident either through radio-collared animals or from periodic census survey work. This also highlights the need, in management, to apply more than one technique to assess wildlife habitat values.

Use of radio-collared females for this study suggests it is likely that the core range assessment through the kernel analysis will not adequately describe concentration areas for sexually segregated mature males. However, since population growth rates are most sensitive to female fitness (Gaillard *et al*., 2000), and assuming that habitat occupancy does affect fitness, reductions in winter habitat quality for females is likely more important to the long-term conservation of the Carcross herd than human land use impacts on male winter habitat quality. Pooling males and females may in fact create more uncertainty in resource selection because of possible sexual segregation of males and females in winter.

Implications for management

Identification of important habitat types and core winter ranges are important components of the management program for the recovery of the Carcross caribou herd. However, it is also essential to maintain connectivity to ensure that caribou are able to move among important winter and other seasonal habitats. Refined habitat assessments and evaluation of detailed movement information from GPS collars should be completed as an essential component of the Carcross herd habitat assessment.

Core management areas should be designated within the caribou winter range where management is directed towards retaining high value lichen habitats for caribou. Although we anticipate an additional three years of information from existing radio-collars, we suggest the 85% kernel home range estimate to be the best representation of a core area for this herd. However, important lichen dominated stands outside of the kernel range must also be identified and incorporated into a final (connected) core winter range.

Over the entire winter range, development activity should be redirected from lichen dominated vegetation types (ONLi and OP) as an important part of any mitigation and cooperative management strategy. These habitats are most at risk as they are under-represented on the balance of the unencumbered public lands and over-represented within the private and ZOI portion of the land base. The potential for the additional influence of human activity (ZOI) must also be considered where development activities are contemplated adjacent to lichen dominated caribou habitat. The strategy of leaving large undisturbed tracts of important habitat for caribou (Racey & Armstrong, 2000; Smith *et al*., 2000; Morgantini & Schmiegelow, 2004) is of limited value for this range due to its configuration and proximity to centres of human habitation. By identifying the remaining lichen dominated habitats where relatively little activity has occurred (i.e., outside of the current ZOI) as environmentally sensitive habitats, we can inform and collaborate with development interests to redirect activities to other appropriate locations.

Finally, it is essential that all levels of government (Territorial, Provincial, Municipal, and First Nation) work in conjunction with boards, councils and resource users towards an integrated land management strategy for resources in the greater Whitehorse area. Retaining caribou on this landscape into the future will require focused and directed management of habitats and land use on this winter range.

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Appendix. Zone of Influence identified for land use activities identified in the Carcross caribou winter range. Range of buffer widths are associated with estimated level of intensity for each activity. Only the lower buffer width was applied for ZOI calculation on the Carcross caribou winter range (after Applied Ecosystem Management Ltd. 2004).

Feature Class Code	Feature Type	Zone of Influence buffer width (m)			
		Lower	Middle	Upper	Original Source
AG	Agricultural Land	250	500	500	Professional Opinion
AG	Grazing Lease	0	250	500	Profession Opinion
IN	Cut Blocks	250	500	900	WCACSC*
IN	Electrical Utility Corridor	500	500	500	UNEP (2001)
IN	Excavation Sites	250	500	900	Professional Opinion
IN	Mine Site/Tailings (inactive)	250	250	250	Professional Opinion
IN	Survey Cut Line	0	250	500	WCACSC
RE	Backcountry Camp	900	900	900	Professional Opinion
RE	High Use Trail	500	500	500	WCACSC
RE	Low Use Trail	250	250	250	WCACSC
RE	Moderate Use Trail	500	500	500	WCACSC
RE	Winter Recreational Areas	Exclude polygon	Include polygon	Include polygon	Professional Opinion
TR	Airstrip	500	900	1000	UNEP (2001)
TR	Primary Road	500	900	1000	UNEP (2001)
TR	Railroad (disused)	500	500	500	Professional opinion
TR	Rough Road	500	500	500	WCACSC
TR	Rural Road	250	250	250	WCACSC
TR	Secondary Road	500	900	1000	UNEP (2001)
TR	Subdivision Road	250	500	500	WCACSC
UR	Commercial /Industrial	900	900	900	UNEP (2001)
UR	City of Whitehorse	0	0	0	Professional Opinion
UR	Public Recreation	500	500	500	Professional Opinion
UR	Public Service	900	900	900	UNEP (2001)
UR	Rural Residences	900	900	900	UNEP (2001)
UR	Urban Residences	900	900	900	UNEP (2001)

* WCACSC – West Central Alberta Caribou Steering Committee.