South Jasper Woodland Caribou Research Project
Progress Report for 2004-2005

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Executive Summary

Woodland caribou (*Rangifer tarandus caribou*) are declining through much of their range across Canada. Within Canada, there are five populations of Woodland caribou. The Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2002) rates these populations as *Endangered* (Atlantic-Gaspesie, < 200 animals), *Threatened* (Southern Mountain and Boreal), *Special Concern* (Northern Mountain), and *Not at Risk* (Newfoundland). Woodland caribou in Jasper National Park belong to the *Threatened* Southern Mountain Population.

The South Jasper Woodland Caribou Research Project started in 2001 to address the following objectives:

1. Establish confidence limits around population estimates, survival rates, and calf recruitment rates to determine whether the caribou population in South Jasper is decreasing.
2. Quantify the level of genetic isolation of caribou in Tonquin, Maligne, and North Banff.
3. Determine what topographic and vegetative factors affect the caribou distribution and then create predictive maps of caribou habitat quality.
4. Examine how people affect caribou habitat quality.
5. Determine whether caribou are subject to higher predation risk in winter because of wolf access to caribou range on ploughed roads and packed ski trails.
6. Identify factors affecting terrestrial and arboreal lichen occurrence and develop fire management guidelines to protect or improve lichen abundance.
7. Communicate research results to the public.
8. Use research results to assist with caribou recovery.

PRELIMINARY RESULTS:

<u>Radio-collaring:</u>

- Retrieved data from 7 GPS collared caribou in Fall 2004. Unable to retrieve data from 3 GPS collared caribou because of water damage (two caribou died in water).
- Retrieved data from 3 GPS collared wolves. Batteries failed prematurely. One wolf dispersed from Sunwapta Falls to the north east of JNP.
- Radio-collared eleven caribou in Fall 2004 (10 GPS, 1 VHF). Only one group of caribou in the Maligne Range therefore redistributed collars (3 Maligne, 4 Jonas Pass, 4 Tonquin).
- Placed GPS and VHF collars on wolves such that there was one GPS and one long lasting VHF collar on the Signal, Medicine, and Maligne (new) packs. In late winter we placed an additional GPS collar on the Signal Pack. One Signal wolf dispersed east of Saskatchewan Crossing where it was killed outside BNP.

<u>Population Estimates</u>

- Fall 2004 population estimate: 100 caribou (95% C.I. 56-336). Found 43 caribou and 3 of 7 radio-collared caribou. Missing caribou were in treed areas of the upper subalpine. Patchy snow and harsh light conditions created difficult survey conditions.
- Fall 2003 survey population estimate: 107 caribou (95% C.I. 86-174). Found 78 caribou and 8 of 11 radio-collared caribou.
- 1988 minimum number: 153 (population guestimate 175-200)
- Recommend evaluating the benefits of conducting population surveys in mid-summer when caribou are almost exclusively in the alpine.

Calf recruitment

- Calf recruitment was high in March 2004 and 2005: 32 calves per 100 cows (95% CL = 15-53) in 2004; 23 calves per 100 cows (95% CL = 11 – 40) in 2005.

Survival

- Caribou were 3.8 times more likely to survive from 2001-2005 compared to 1988-1991. Survival rates were very low from 1988-1991 (12 mortalities in 29 caribou years) and were relatively high from 2001-2005 (3 mortalities in 29 caribou years).
- Low sample sizes lead to large uncertainty in survival estimates. In 2001-2005, annual survival rate was 0.932 (95% C.I. = 0.566-0.989).

Genetic diversity

- Second year of DNA samples were sent for analysis, but we have not received the analysis.
- From the few samples sent in the first year, preliminary results suggest that caribou in the Maligne and Tonquin have high genetic variability (indicates movement between subpopulations) but had surprisingly different alleles (genetic composition). Caribou in Banff had 3 times less genetic variability compared to caribou in Jasper.
- No radio-collared caribou from 1988-1991 (29 caribou years) or from 2001-2005 (29 caribou years) have travelled between the Maligne and Tonquin, north of Highway 16, nor south of Highway 11 into Banff.

Caribou habitat and trails

- Created models of caribou resource selection for each ecoregion (Alpine and Subalpine) and for each season: Summer (June-August), Fall (September-November), Winter (December-February), and Spring (March-May). Created predictive maps of caribou occurrence for Banff and Jasper.
- Added distance to low and medium use trails to the resource selection models.
- Caribou had stronger negative associations with trails in the Alpine compared to the Subalpine.
- 80% of caribou had negative associations with trails in the Alpine during Summer and Fall.
- Less than 40% of caribou had negative associations with trails in the Alpine during Winter and Spring and in the Subalpine (except Winter when ~50% of the caribou avoided trails)

Wolf travel routes and Trails

- Wolves selected roads as travel routes in all seasons except Summer.
- Wolves selected trails as travel routes in all seasons except Fall.
- Wolves more strongly selected trails at high elevation compared to low elevations in Winter and Spring.

Caribou, wolves, and people

- Two mechanisms may explain why caribou were negatively associated with trails: (1) avoid the presence of people on trails (2) reduce their risk of predation from wolves that travel on trails. The first mechanism (avoidance of people) is more likely in the alpine during summer and fall. The second mechanism is more likely in the subalpine during winter.

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Acknowledgements

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1. Introduction

Woodland caribou (*Rangifer tarandus caribou*) are declining through much of their range across Canada. Within Canada, there are five populations of Woodland caribou. The Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2002) rates these populations as *Endangered* (Atlantic-Gaspesie, < 200 animals), *Threatened* (Southern Mountain and Boreal), *Special Concern* (Northern Mountain), and *Not at Risk* (Newfoundland). Woodland caribou in Jasper National Park belong to the *Threatened* Southern Mountain Population.

This report summarizes the results from the first three years of the South Jasper Woodland Caribou Research Project. This project was initiated to determine why the number of caribou in South Jasper has declined and what management actions could stabilize the population. Due to the timing of collar deployment and data retrieval (Fall), this report contains two full years of data collected from GPS collared caribou and intermittently collared wolves. The results presented in this report are preliminary and may change after the final two years of data have been collected. GPS collars used were the Lotek 2200 and 3300 series. GIS layers were compiled in ArcInfo® and GRASS (http://grass.itc.it/). All statistical analyses were conducted in R 2.01 (http://cran.stat.sfu.ca) (Ihaka and Gentleman 1996).

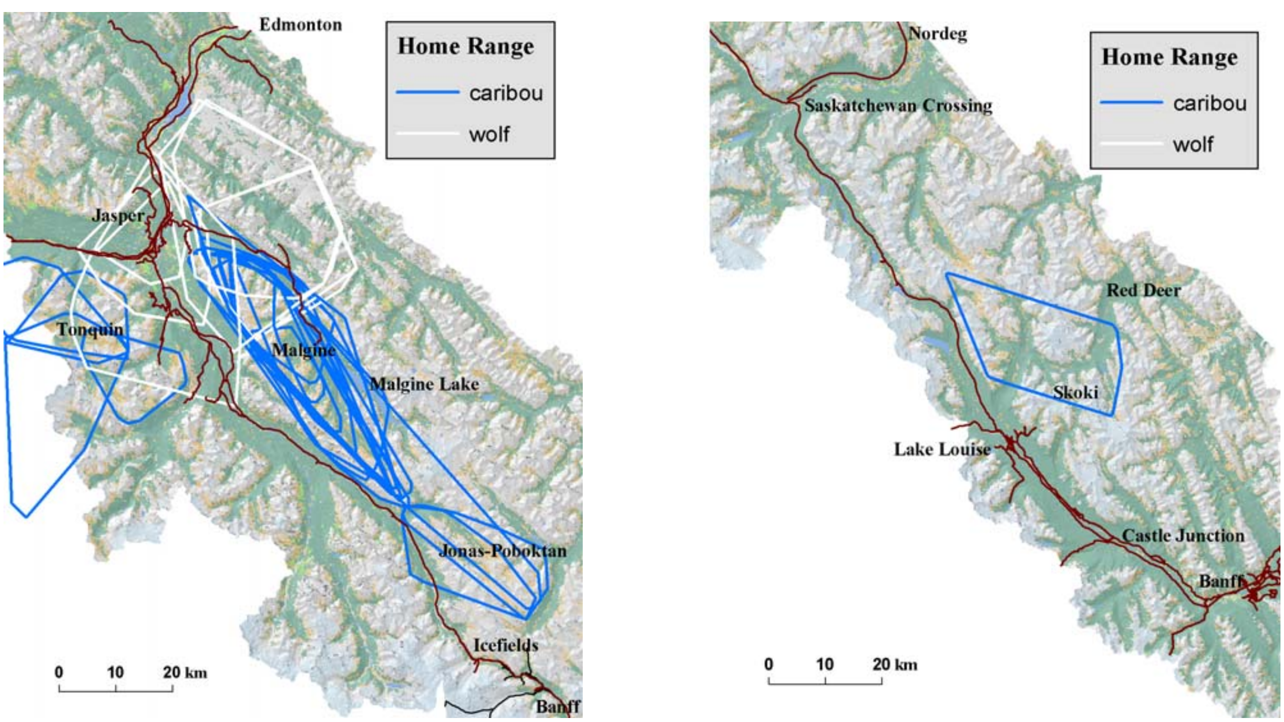
2. Caribou and wolf captures

In Fall 2001 we conducted a pilot study to determine the effectiveness and reliability of GPS collars to describe caribou habitat selection and movements relative to people, predators, and snow conditions. Two caribou were fit with conventional VHF collars and two caribou were fit with GPS radio-collars that automatically recorded the caribou's location every three hours from October through March. The GPS collars radio-collars worked well and were chosen as the primary method of collecting data on caribou distributions in South Jasper. Two workshops were held to create a study design that would best identify threats to the South Jasper Caribou Population (Mercer et al. 2004). These workshops recommended placing ten GPS collars per year on caribou in the Maligne Range for four years. Ten GPS collars represented approximately 20% of the adult female caribou population in South Jasper. After two years of study, a large winter, human-use treatment was recommended to determine how ploughed roads and packed ski trails affect the risk of caribou predation by wolves.

In Fall 2002 (Year 1), seven GPS collars were placed on caribou along the Maligne Range (Figure 1). Only three or four groups of caribou could be found, therefore the remaining three collars were placed in the Tonquin. From Fall 2002 through Fall 2003, none of the caribou died and we retrieved data from all of the collars. However, one of the caribou in the Maligne Range travelled south to Jonas Pass. In Fall 2003 (Year 2), few groups of caribou were found in the Maligne Range. Therefore, five GPS collars were deployed in the Maligne, two in Jonas-Poboktan, and three in the Tonquin. A single GPS collar was placed on a group of four caribou in North Banff National Park. In Year 2, two of the caribou in the Maligne died in water and no data could be retrieved from their collars. An additional collar in the Tonquin inexplicably sustained water damage. Therefore, we retrieved data from seven GPS collars in Fall 2004. In Fall 2004 (Year 3), three GPS collars were placed on the only group of caribou found in the Maligne. Four GPS collars were placed in Jonas-Poboktan. Three GPS and one VHF collars were placed in the Tonquin. Two GPS collars were placed on a group of five caribou in North Banff. We will retrieve data from these collars next Fall (2005). Up until June 2005, one caribou died in the Maligne and one collar has likely malfunctioned in the Tonquin.

Wolves were considered to be an important predator of caribou in winter (Brown et al. 1994). In March 2003 (Year 2), two GPS radio-collars were fit on both the Medicine and Signal wolf packs. All four collars failed between three and eight months after deployment because of factors ranging from punctured GPS antennas to loose rivets. However, data was retrieved from all collars. The GPS collars were refurbished or replaced and were then redeployed along with VHF collars from November 2003 through early January 2004. Two GPS collars were placed on the Medicine Pack, one GPS collar was placed on the Signal Pack, and one GPS collars was placed on a wolf at Sunwapta Falls that was suspected to travel into the upper Maligne. The collars had deficient batteries and all collars failed by July 2004. The Sunwapta wolf was lost while dispersing out of park near the Snake Indian Valley. The remaining three GPS collars were refurbished and redeployed in November 2004. One collar was placed on each of the Signal, Medicine, and a new Maligne Pack. The Medicine and Maligne collars continue to work. The wolves chewed the GPS antenna off the Signal collar but the collar was retrieved after the wolf dispersed and was shot east of Saskatchewan Crossing.

For this report, we used intermittent data through summer and winter for the Signal and Medicine Packs, but lack data for wolves that travelled in the upper Maligne. Historically, wolves did not establish territories in the Maligne Valley. Instead they were thought to make forays up the valley from the Athabasca Valley, often travelling on the Maligne Road (Brown et al. 1994). In the winter of 2002-2003, two wolves established their territory in the valley and reared five pups in the summers of 2003 and 2004. This pack has shifted its territory eastward into the Rocky River, possibly due to low prey densities in the Maligne Valley. In summer 2004, wolves likely denned along Maligne Lake. The following winter they ranged from the Maligne Valley to the Rocky River. At least one of the radio-collared wolves dispersed to the northeast portion of Jasper and we are unsure if wolves have established a den site at Maligne Lake this summer.



a) South Jasper b) North Banff

Figure 1. Home ranges (100% minimum convex polygons) of GPS collared caribou and wolves in a) South Jasper and b) North Banff.

GPS fix rates were higher for caribou (mean = 81.2 %, std = 16.2, range = 31.0-97.3) than for wolves (mean = 59.8 %, std = 21.8, range = 36.8-93.4). A future goal of this project will be to quantify the effects of vegetation and topography on GPS bias and incorporate those biases into habitat selection and movement models (Frair et al. 2004).

3. Population Demographics

3.1 Population Surveys and Calf Recruitment

In 2004-2005 we conducted three caribou surveys. In June and March we calculated calf-cow ratios from groups of caribou associated with radio-collared animals. In late-September or early October we calculated population estimates by scanning for all caribou in the alpine and upper–subalpine areas in South Jasper. The June and March surveys commenced in March 2004, whereas the fall surveys have occurred since 1988 (Brown et al. 1994).

The fall surveys occurred when the caribou congregated in the alpine for the rut and thus when they are easiest to find. The Tonquin, Maligne, and Jonas-Poboktan areas were surveyed using a Bell 206 Jet Ranger flying at approximately 100kmph and 50m above ground level. While flying, the pilot, navigator, and two spotters visually searched for caribou. Telemetry receivers were not used to assist search efforts. When a caribou group was located, the helicopter landed and a 60x power spotting scope was used to classify animals as adult, yearling, or calf. When conditions permitted, animals were sexed based on antler form, presence of penis sheath in males, or the presence of a vulva in females. Yearlings and calves were identified on the basis of body size and form. In 2003 and 2004 radio-collared caribou represented a marked sample of animals. Thus, population estimates and 95% confidence limits were calculated based on the proportion of radio-collared caribou observed on the survey. Confidence limits were calculated using joint hyper-geometric maximum likelihood estimator (Bartmann et al. 1987; White and Garrott 1990; Neal et al. 1993).

In 2003 and 2004, 78 and 43 caribou were observed on the fall population surveys, respectively (Figure 2). In, 2003, 8 of 11 radio-collared caribou were observed, which produced a population estimate of 107 caribou (95% C.I. = 86-174). In 2004, 3 of 7 radio-collared caribou were observed to create a population estimate of 100 caribou (95% C.I. = 56-336). Flight time was similar for this survey (17.5 hrs) compared to other surveys, but harsh light conditions and patchy snow created difficult conditions for spotting caribou. An additional 17 caribou were observed after locating the remaining collared caribou to create a minimum population size of 60 animals. All of the missed caribou were found in treed areas of the upper subalpine. Analysis of GPS collar data indicates that caribou are much more variable in the amount of time spent in the alpine in September-October compared to July (Figure 3). Consequently, future population surveys might be more effective in late July when caribou reliably spend most of their time in the alpine. Another advantage of conducting surveys in July is that annual weather conditions would be more consistent and surveys would not be affected by patchy snow conditions.

Fifteen adult males, 26 adult females, 3 adults (sex unknown), 6 yearlings, and 10 calves were observed on the survey on the fall 2004 survey. Twenty-seven, 11, and 22 caribou were observed in the Tonquin, Maligne, and Jonas-Poboktan regions, respectively. A month later, the capture crew also found just 12 caribou in the Maligne Range.

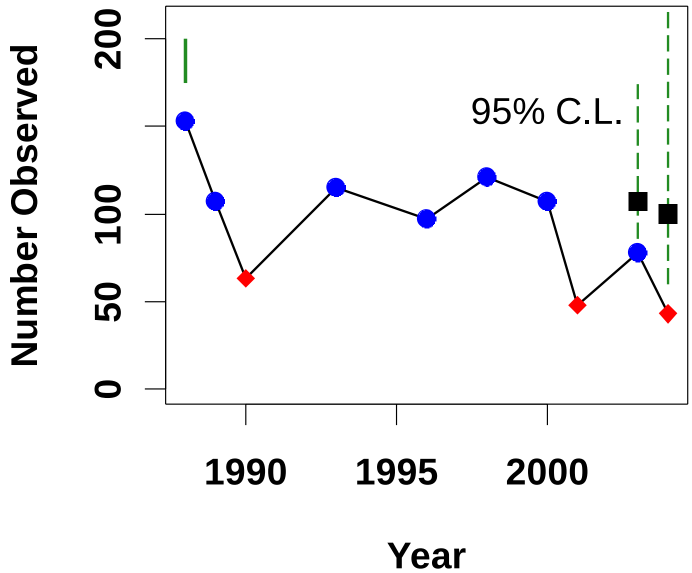


Figure 2. Number of caribou observed on caribou surveys in South Jasper National Park. Blue circles indicate good survey conditions, red diamonds indicate poor survey conditions, black squares indicate population estimates. The solid vertical line (1988) represents a population guestimate. Vertical dotted lines (2003, 2004) indicate 95% confidence limits around the population estimates based on the proportion of radio-collared caribou observed. However, the upper confidence limit for 2004 was 336, which lies off the scale of the y-axis.

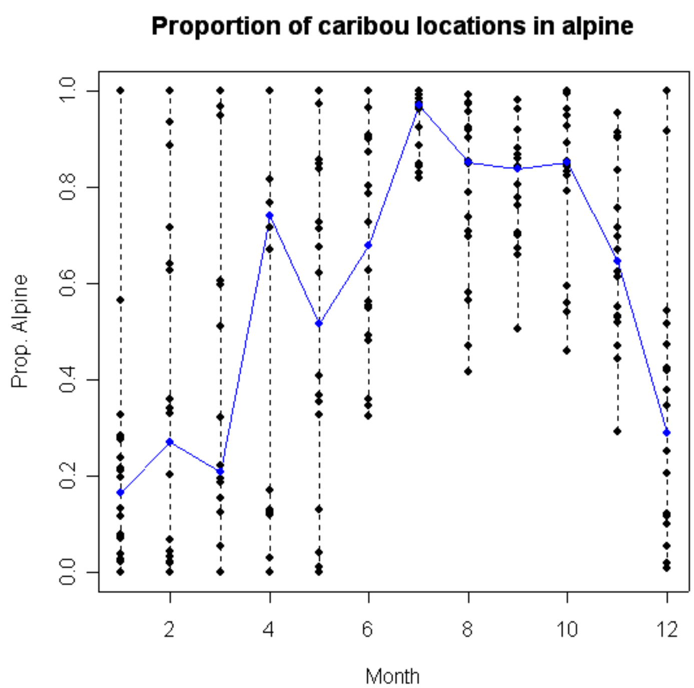


Figure 3. Proportion of caribou locations in the alpine for each month of the year. Black dots indicate individual caribou, the blue line indicates the mean of the individual proportions.

3.2 Calf Recruitment

Commencing March 2004, we counted the number of calves in groups of caribou associated with radio-collared animals in June and March. After calves reach 10 months of age, their mortality rates are thought to be similar to the rates of adult mortality (Wittmer 2004). In 2004, four of fifteen cows had calves in June (27 calves per 100 cows; 95% CL = 5-63) (Figure 4). However, on the subsequent fall survey 10 of 26 cows had calves (38 calves per 100 cows; 95% CL = 26-56). On the March 2005 survey, 6 of 26 cows had calves (23 calves per 100 cows, 95% CL = 11 – 40). Although the proportion of calves observed in March 2005 was slightly lower than March 2004 (32 calves per 100 cows, 95% CL = 15-53), these recruitment rates were similar to other stable Woodland caribou populations (McLoughlin et al. 2003). High uncertainty in the June calf-cow ratios make it difficult to determine what time of year most calves are killed. In other areas, caribou often have parturition rates above 85% (Wittmer 2004) and most calves are killed during the summer (Wittmer 2004; Gustine).

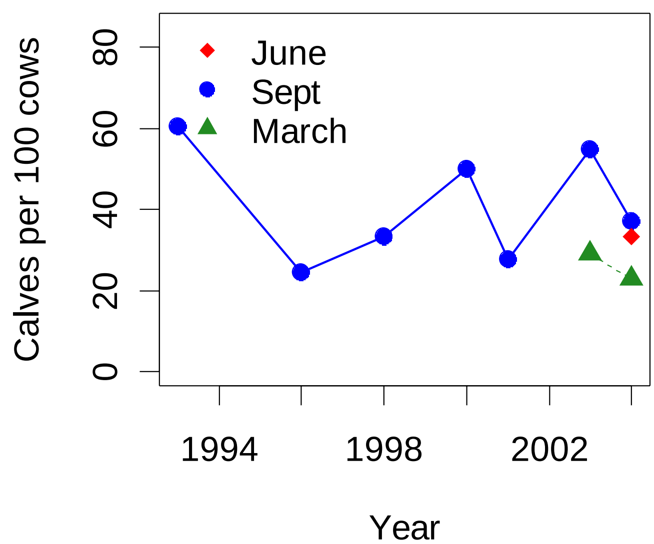


Figure 4. Calves per 100 cows observed on the fall population surveys and spring calf surveys of radio-collared caribou in June, September, and March. Points from March surveys are placed in the same biological year as the June and September surveys.

3.3 Survival and Mortality

Caribou survival rates were higher from 2001-2005 compared to 1988-1991 (Figure 5). Caribou were 3.8 times more likely to survive in 2001-2005 compared to 1988-1991 (Cox proportional hazard regression, p-value = 0.038). However, low sample sizes lead to large confidence intervals around the baseline hazard. Annual survival rates from 2001-2005 were 0.932 (95% C.I. = 0.566-0.989) whereas annual survival rates from 1988-1991 were 0.663 (95% C.I. = 0.420-0.823). Since 2001, only 3 of 18 radio-collared caribou died in 29 caribou years, whereas 12 of 21 radio-collared caribou died in 29 caribou years from 1988-1991 (Brown et al. 1994). The large confidence intervals indicate that our current estimates of caribou survival lack precision.

From 1988-1991, 9 radio-collared caribou died from predation (6 wolf, 1 bear, 2 unknown) and 3 from natural causes (1 capture, 1 breech birth, 1 rut-related). From 2001 to 2005, 3 radio-collared caribou died from unknown causes. The collar of one was retrieved out of the upper Maligne River in June 2004. Because radio-collars cannot slip over a caribou's head, the caribou was either killed by a predator or was scavenged after drowning in the river. The second unknown mortality occurred at Medicine Lake in late June or early July 2004. The collar stopped working in June 2004, but was found by a fisherman in the water of Medicine Lake in September. The carcasses of the caribou and her small calf were relatively intact. Wolves were active in this area and may have contributed to their mortality. The third unknown mortality occurred in January 2005. The mortality switch on the collar failed to trigger, so the collar was not retrieved until March. The collar was found on top of the snow between two avalanche chutes where wolverine and marten had deposited it. Likely causes of death were avalanche or predation by wolverine.

From 2001-2005, nine other caribou mortalities were reported of which six were confirmed. Of the confirmed mortalities, three were killed by collisions with vehicles and wolves killed the other three (two in April, one in July). In April 2005, two wolves killed two caribou near Poboktan Pass after chasing the caribou for several kilometres in the alpine. The wolves had a distinct advantage because the caribou penetrated through a snow crust while the wolves travelled on the surface. Because snow crusts form most years in late March – April, caribou might be especially vulnerable to predation at this time of year. Three mortalities from 1988-1991 also occurred in April and were attributed to wolf predation. These results differ from other areas where most caribou mortalities occur in summer (Wittmer 2004).

Four caribou that were necropsied from 1988-1991 were in poor condition, whereas four caribou that were necropsied from 2001-2005 appeared healthy. It is unclear why survival rates and caribou conditions differ for the two time periods. One explanation is that winters may have been more severe in the 1988-1991 compared to 2001-2005 (K. Brown pers. comm.). These severe conditions may have forced the caribou to lower elevations where they were more susceptible to predation from wolves.

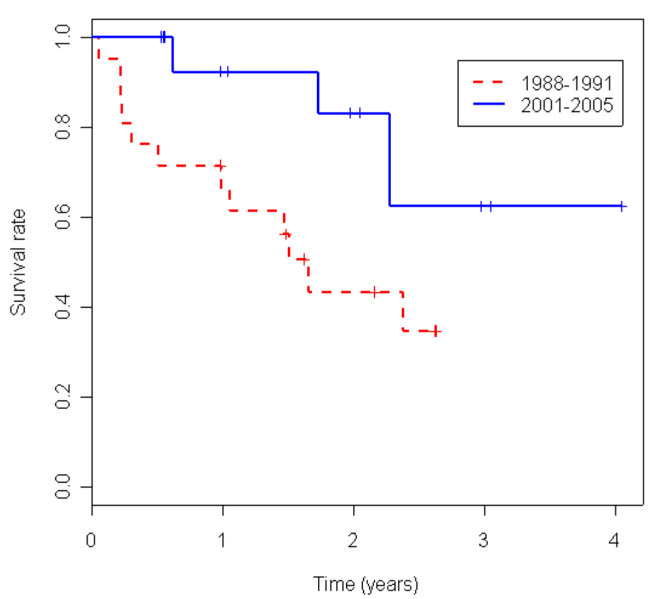


Figure 5. Cumulative survival rates of radio-collared caribou from 1988-1991 and from 2002-2005.

3.4 Genetic diversity

The persistence of wild animal populations depends in part on the ability of animals to migrate between subpopulations. Isolated subpopulations commonly have low genetic diversity and are more susceptible to extinction because recolonization cannot occur after catastrophic events, they are less able to adapt to environmental change, and they may have lower fertility, productivity, and disease resistance (Soule 1980).

We sent DNA samples of caribou to Wildlife Genetics International to examine the genetic diversity of caribou in Jasper and Banff and to later compare with caribou population in British Columbia and Alberta. Preliminary results based on a small sample from the previous year suggest that caribou in the Tonquin and Maligne have high genetic diversity but have surprisingly different alleles (genetic composition). Genetic diversity from the single sample in North Banff National Park was three times lower than the genetic diversity of samples from Jasper. We have not yet received the results after the addition of captures from Fall 2004. In other areas, Boreal caribou have relatively high genetic diversity (McLoughlin et al. 2004) several of those caribou populations are declining (McLoughlin et al. 2003).

None of the radio-collared caribou from 1988-1991 (29 caribou years) or from 2001-2005 (29 caribou years) have crossed between the Maligne and Tonquin valleys, across Highway 16 (Yellowhead Highway) to the north, nor south across Highway 11 to Banff National Park. However, caribou in the Tonquin repeatedly traveled into the upper Fraser River of British Columbia during the winter. Eighty-seven percent of the collared caribou were female, so these results may not represent male movements. If caribou in the Maligne and Tonquin are isolated populations, then they may be more susceptible to extinction.

4. Habitat, people, and wolves

This chapter has three objectives:

1. Determine what constitutes high quality caribou habitat and predict where it occurs. Then determine how trails affect where caribou occur.
2. Determine how trails affect where wolves occur.
3. Based on 2 & 3, determine the relative influence of human activity and predation risk on the spatial distribution of caribou.

4.1 Caribou Habitat and Trails.

4.1.1 Caribou RSF Methods

Caribou distributions in Banff and Jasper National Parks depend on where preferred foods occur, where they are at risk of predation, and how they respond to human activity. We first identified what constitutes important caribou habitat by comparing topographic and vegetative resources at caribou GPS locations to random locations within each caribou's home range (100% minimum convex polygon) using multiple logistic regression. The resulting models are commonly referred to as Resource Selection Functions or RSF's (Manly et al. 1993). Explanatory variables for the analysis and their transformations (Table 1) were selected based on predicted biological responses and empirical frequency distributions. One assumption of RSF analyses is that an animal's resource selection does not change during the period of data collection. Caribou likely selection of foods and habitats likely depends on the time of year and whether they were in the alpine or subalpine. Therefore, we conducted separate analyses for the alpine and subalpine ecoregions as well as for each season: Winter (December – February), Spring (March – May), Summer

(June – August), and Fall (September – November). Within each stratum we paired one random location with each caribou location. We prohibited the random locations from occurring in places where caribou never travel (ice, lakes, and towns). The random locations were also excluded from areas within 100 m of caribou locations to help differentiate resources used and not used by caribou and to increase our power to estimate resources selected or avoided by the caribou.

After creating habitat related RSF models, we examined caribou responses to trails. We added trail covariates to the habitat related RSF models and retaining them if they had robust p-values < 0.05. Earlier analyses suggested that caribou were less likely to occur near trails (Mercer et al. 2004). Anecdotal observations both corroborate and refute these results. Some caribou were reported to flee from people while others were reported to be ambivalent to the presence of people. Therefore, we examined individual variation caribou responses to trails. We added distance to low-use and medium-use trails to each RSF model, ran the model for each individual caribou, and retained the trail β coefficients if robust p-values were < 0.05. We then tested for the effects of trail-use (low, medium), season (winter, spring, summer, fall), ecoregion (alpine, subalpine), and availability (proportion of random locations within 1 km of the low or medium use trail) on the β coefficients using linear models.

Table 1. Explanatory variables used to identify important caribou habitat and their spatial responses to people

Variable	Description
elev	Elevation above sea level (km)
aspect.s	Aspect in N-S direction; S = 1, N=-1; Calculated as –1 * cosine(aspect) and Slopes < 5^0 = 0.
aspect.w	Aspect in E-W direction; W = 1, E=-1; Calculated as –1 * sine(aspect) and Slopes < 5^0 = 0.
slope	Slope in degrees
slope2	Slope in degrees squared
curve	Curvature. Positive values are upwardly convex (e.g. ridge). Cell size = 120 m
tri	Terrain ruggedness index; sqrt(sum of (elevation – surrounding elevations)^2). tri.flat (tri <= 50 m), tri.medium (tri > 50 m and <= 116 m), reference category is tri > 116 m.
solar	Solar radiation calculated at the equinox. Solar radiation accounts for latitude, slope, aspect, shading from adjacent topography throughout the day, and radiation lost in the atmosphere (Kumar et al. 1997). (0 – 29 MJ m^{-2} day^{-1})
landcover	Landcover map created using remote sensing by Greg McDermid, U of C. Categories include v.conifer.closed, v.conifer.open, v.barren, v.herb, and v.shrub. Conifer.closed was the reference category for the subalpine ecoregion, barren was the reference category for the alpine ecoregion.
p_herb	Percentage of herbaceous land cover within an area of 1 km^2
p_shrub	Percentage of shrub land cover within an area of 1 km^2
open	Non-forested areas (Yes = 1, No = 0)
edge	Within 100 m of an open area; Yes=1 or No=0
lai	leaf area index
riparian	Within 100 m of a stream; Yes=1, No=0
fire150	Forest age greater than 150 years old; Yes = 1, No = 0
treeline	Distance to tree line (km).
trail	On trail (within 50 m) (Yes = 1, No=0)
road	On road (within 50 m) (Yes = 1, No = 0)
trail-low	Distance to low-use trails (1-10 groups per month). Trails were assumed to have no effect on animals beyond 0.5 km; therefore distances greater than 0.5 km were assigned a value of 0.5.
trail-medium	Distance to medium-use trails (> 11 groups per month). Trails were assumed to have no effect on animals beyond 0.5 km; therefore distances greater than 0.5 km were assigned a value of 0.5.

To create the habitat related RSF models we chose to use forward stepwise selection with robust p-values rather than an Information Theoretic approach (Burnham and Anderson 1998) for several reasons. First, GPS locations were serially correlated and individual caribou rather than individual locations represent the independent samples. This autocorrelation has two effects: first it artificially reduces standard errors and p-values and resulting in high Type I errors (false positives). Second, models selected with Akaike Information Criterion (AIC) and autocorrelated data become over parameterized and penalization methods (e.g. QAIC) are not well developed. A final reason for choosing stepwise selection over AIC is that our large number of plausible explanatory variables (Table 1) would contribute to an undesirable, large number of candidate models. For these reasons, we used manual forward stepwise selection. At each step we selected explanatory covariates that had the most biological relevance and that had the lowest robust p-value. Robust p-values were calculated using Huber-White corrections with individual caribou representing independent samples (Huber 1967; White 1982). For caribou that were collared for more than a single year, each year represented an independent sample.

We assessed overall model performance two ways. The ability of each model to accurately differentiate between caribou and random locations was assessed using a receiver operating characteristic (ROC) curve (Hosmer and Lemeshow 2000). This test calculates the ability of the model to differentiate use and random locations for predicted probabilities ranging from 0 to 1. ROC values of 0.5, 0.7, 0.8, and 0.9 indicate no, acceptable, excellent, and outstanding predictability respectively (Hosmer and Lemeshow 2000). The second method of evaluating model performance used a form of k-fold cross validation (Boyce et al. 2002). Individual caribou were sequentially omitted from the final RSF model. We then created predicted values for the omitted caribou, and calculated spearman ranked correlation coefficients between the frequencies of observed and predicted values of the omitted caribou. We finally calculated the mean and standard deviation of the correlation coefficients for all caribou. High correlation coefficients indicate strong model performance; high standard errors indicate high variability in resources selected by caribou and less predictable models.

Models included 2D and 3D GPS locations and did not account for the effects of GPS bias associated with rugged terrain and dense canopy cover (Frair et al. 2004). Similarly, we did not account for GPS error of the caribou locations. Future RSF models need to account for both GPS bias and GPS error. We omitted locations that occurred in British Columbia (west of the Tonquin) because we lacked data layers for that area. In all analyses, multicollinearity among covariates was avoided by calculating variance inflation factors (VIF) for potential models and then removing covariates with VIF's greater than 3. Quadratic transformations ($x + x^2$) had high VIF's but were retained in the models.

4.1.2 Caribou RSF Results

The caribou RSF models differentiated between caribou and random locations decently but not exceptionally well (ROC range = 0.783 – 0.859, cross-validation mean correlation coefficients range = 0.772 - 939). Models for the alpine performed better (higher mean cross validation correlation coefficients with lower standard deviations) than models for the subalpine (Table 2). Poorer performing models are likely missing important covariates selected by caribou (such as food layers) or there was high variability in resources selected by the caribou. RSF models were created using data from GPS collared caribou in South Jasper and one caribou from North Banff. K-fold cross validation indicated that the models performed well within the Banff caribou's home range (k-fold mean = 0.848, k-fold std = 0.091, range = 0.701-0.937). However, visual inspection of maps generated from models indicates that Banff may contain more high quality subalpine habitat than Jasper (Appendix I, Figure 11, Figure 12), yet Banff has

Table 2 β coefficients for models of caribou resource selection. "Ref" denotes the reference category of land cover. "n" indicates the number of caribou locations for each model. Between 17 and 21 caribou were used to create each model. Models were validated using ROC and K-fold cross validation.

	Subalpine				Alpine			
Variable	**Summer**	**Fall**	**Winter**	**Spring**	**Summer**	**Fall**	**Winter**	**Spring**
Intercept	-13.821	-19.983	-19.644	-15.963	-9.120	-12.640	-3.064	-7.467
elev	5.744	10.273	8.311	3.769	1.474	2.639		
slope	-0.030	-0.051			0.045	0.015	0.057	0.095
slope2					-0.002	-0.001	-0.002	-0.003
aspect.w	0.485	0.248				0.338		
tri.flat					0.535	0.960	-0.372	
tri.medium			0.343	0.759	0.304	0.615	0.534	0.522
curve	0.005			0.118	-0.016	-0.028	0.055	0.030
curve2					-0.006	-0.002	-0.007	
v.conifer.closed	ref	ref	ref	ref				
v.conifer.open								
v.barren		-1.643	-0.697		ref	ref	ref	ref
v.herb	1.791	0.970		-8.368	0.856	1.493	1.090	0.993
v.shrub	0.853			-3.040	1.062	1.507	0.701	0.515
p_herb	0.032				0.043	0.037		
p_shrub			-0.040	-0.095		0.025	-0.010	
riparian								
lai			0.613		0.038			
lai2			-0.066					
dtree	-0.292				-0.417	-0.600	-1.652	-1.136
edge	0.454		-0.395	-1.104				
fire150	-0.682		0.547					
trail-low			4.104	6.272		5.659	6.312	5.595
trail-medium	5.557			12.301	8.914	3.045		8.785
n	1095	1684	4091	1058	4534	5126	2033	2611
ROC	0.854	0.939	0.787	0.823	0.836	0.863	0.785	0.772
K-fold mean	0.780	0.724	0.832	0.760	0.758	0.877	0.745	0.830
K-fold std.	0.190	0.174	0.163	0.102	0.056	0.034	0.059	0.059

fewer caribou. A couple reasons for this discrepancy might include: (1) The amount of high quality alpine habitat affects where caribou establish their home ranges more than the amount of high quality subalpine habtat. (2) Elevation was an important covariate in all subalpine models. Because valley bottoms in Banff are 300 m higher than Jasper, models would predict more favourable subalpine habitat in Banff. (3) Land cover maps did not differentiate between moist alpine meadows (favoured by caribou) from dry, grassy slopes (favoured by elk and sheep) found in eastern Banff. Similarly, the land cover maps did not differentiate between pine, spruce, and subalpine fir forests. These reasons are speculative and require further investigation.

Resources selected by caribou depended on the season and ecoregion. Complete results (β coefficients, standard errors, robust p-values) for each RSF model with the addition of roads, trails, and campgrounds can be found in the appendix (Table 6). When in the subalpine, caribou selected high elevations during all seasons and selected westerly aspects and shallower slopes during summer and fall (Table 2). They selected broad ridges (positive curvature) during summer and spring. Compared to rugged terrain, caribou selected moderately rugged terrain (winter and spring). Compared to coniferous forests, they avoided barren ground (fall, winter), selected for herbaceous meadows (summer and fall), avoided herbaceous meadows (spring), and selected for shrub meadows (summer). They selected for areas with a high percentage of herbs within 1 km^2 area (summer) and avoided areas with high percentages of shrubs (winter, spring). They selected areas with moderate leaf area index (winter) and areas close to treeline (fall). They selected areas within 100 m of open areas during summer but avoided these areas during winter and spring. They selected forests older than 150 years in winter but avoided these areas in summer.

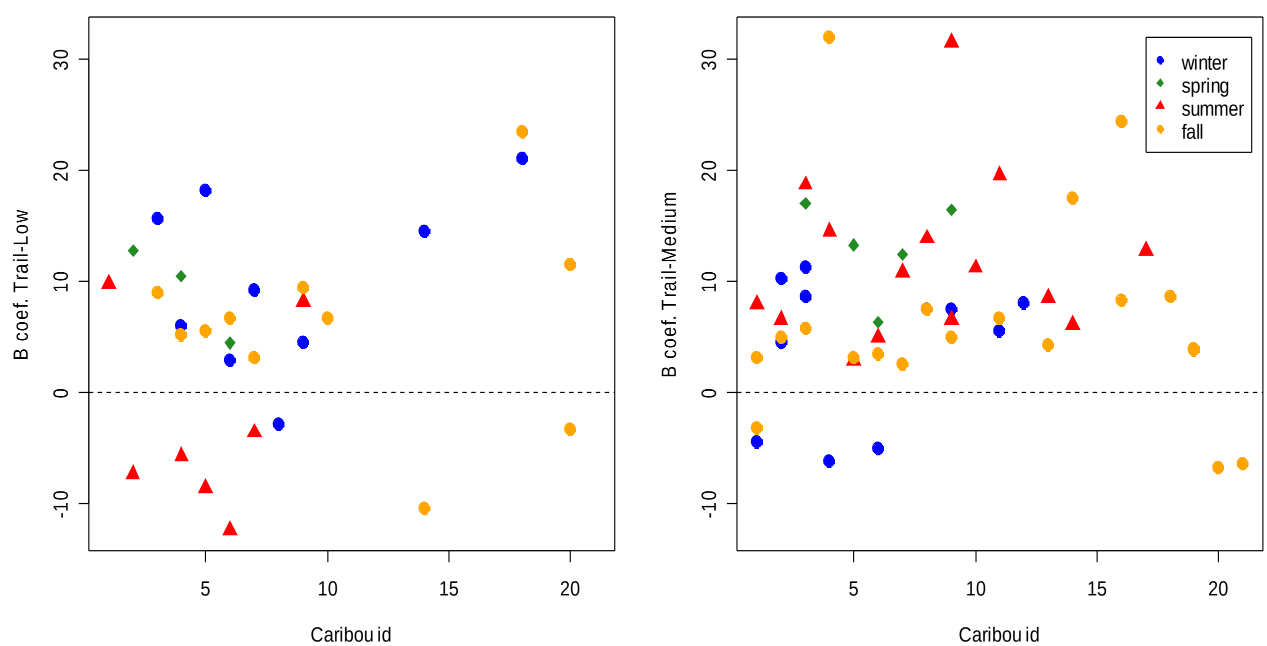
When in the alpine, caribou selected high elevations during summer and fall and westerly aspects during the fall. They selected moderate slopes during all season. Compared to rugged terrain, caribou always selected moderately rugged terrain and sometimes selected flat terrain. They avoided steep gullies and ridges during all seasons except spring when they selected broad ridges (positive curvature). Compared to barren ground, the caribou always selected herbaceous and shrub meadows. They generally selected for areas with a high percentage of herbs within 1 km^2 area (summer and fall), they selected areas with high percentages of shrubs in fall but avoided these shrub areas in winter. They selected areas with high leaf area index in summer and areas close to tree line during all seasons.

The habitat related RSF models (Table 2) do not explicitly specify what foods caribou select at different times of the year nor do they account for selection of areas with low predation risk. We assumed that our topographic and vegetation related covariates are correlated with caribou foods, such as terrestrial and arboreal lichens. We lack maps for the distribution and abundance of these species, but L. Shepherd is examining factors that affect the abundance of caribou foods and plans to create predictive layers of those foods that can then be incorporated into more mechanistic RSF models. Similarly, Jasper lacks fine scale vegetation maps. Land cover, canopy cover, leaf area index, and species composition maps used in the analysis were created from remote sensing. These maps appear to be more accurate than Jasper's Ecological Land Classification, but they are currently limited in their ability to differentiate some forest types (e.g. pine and spruce, shrub and aspen). Future RSF maps will improve as the maps derived from remote sensing

Caribou in Jasper are thought to feed on terrestrial lichens, arboreal lichens, *Ledum* spp., *Equisetum* spp., and other plants during winter (Thomas 1999). In other Woodland caribou studies, the foods selected by caribou varied depending on their geographic region. Caribou in west-central British Columbia selected for pine dominated forests where they fed primarily on terrestrial and secondarily on arboreal lichens (Johnson et al. 2001). Moreover, terrestial lichens were most prevalent in moderately open stands of lodgepole pine between 70 and 150 years old (Coxson & Marsh 2001). In several areas of British Columbia and Alberta caribou selected caribou selected mature stands of spruce and subalpine fir where they fed on arboreal lichens (Goward 1998; Poole et al. 2000; Terry et al. 2000; Apps et al. 2001; Szkorupa 2002).

When trail covariates were added to the habitat based RSF models, distances to low use trails (1-10 groups per month) or medium use trails (> 11 groups per month) were important predictors in seven of the eight models (Table 2). Caribou were negatively associated with areas near low-use trails in the subalpine during winter and in the alpine fall, winter, and spring. Caribou were negatively associated with medium-use trails in the subalpine during summer and spring and in the alpine during summer, fall, and spring. To better understand individual variability in responses to trails we created RSF models using covariates in Table 2 for each caribou. The number of caribou in a given season ranged from 17-21. We then added distance to low-use and medium-use trail to each model and retained the covariate if its p-value was less than 0.05. We created 156 models, of which a higher number of medium-use trails (n = 51) had significant p-values compared to low use trails (n = 30). Of these models, 8 and 6 models had positive associations with low and medium-use trails and 22 and 45 had negative associations with low and medium-use trails, respectively (Figure 6). The value of the β coefficients (strength of association) was higher in the alpine compared to the subalpine (linear model, $\Delta AIC = 3.6$, $\beta = 4.673$, p-value = 0.020) but did not depend on level of trail use (ΔAIC = 0), season (ΔAIC = -3.4), nor the amount of available habitat influenced by trails (ΔAIC = 0). The percentage of caribou with negative associations to low or medium-use trails depended on both ecoregion and season (Figure 7). Most caribou (~80%) had negative associations to trails in the alpine during summer and fall. Less than half of the caribou had negative associations to trails in other seasons and ecoregions (except in the subalpine during winter). More caribou had negative associations to trails in the alpine compared to the subalpine in all seasons except winter.

We evaluated the potential effect of trails on caribou habitat quality by overlaying trails and a 500 m buffer (Dyer et al. 2001) onto a predictive map of caribou occurrence (Appendix I, Figure 11). We then calculated the area of each habitat class within and beyond the 500 m buffer (Figure 8). We confined the analysis to the composite home ranges of caribou in the Tonquin, Maligne, and North Banff. Similarly, we confined the analysis to the alpine where trails have a larger effect on caribou than the subalpine and to the summer habitat map when most caribou are affected by trails. Habitat classes (very low, low, high, very high) were defined using the quartiles of predictions from each model. Within the caribou ranges, only 30% of the caribou range consisted of high or very high quality habitat (Figure 8). Moreover, 23% of the high and very high quality habitat occurs within the 500 m influence of trails.



a) low-use trail b) medium-use trail

Figure 6. β coefficients of individual caribou for a) low and b) medium use trails by season. Positive β coefficients indicate that caribou are more likely to occur further from trails up to distances of 0.5 km. Only coefficients with p-values less than 0.05 are shown.

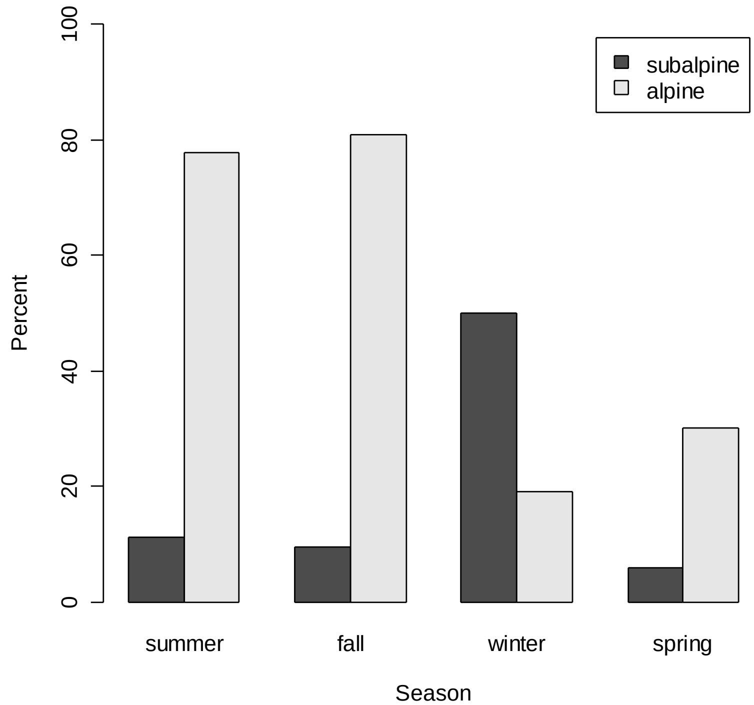


Figure 7. Percentage of caribou (n = 17-21) with negative associations to low or medium-use trails by season and ecoregion.

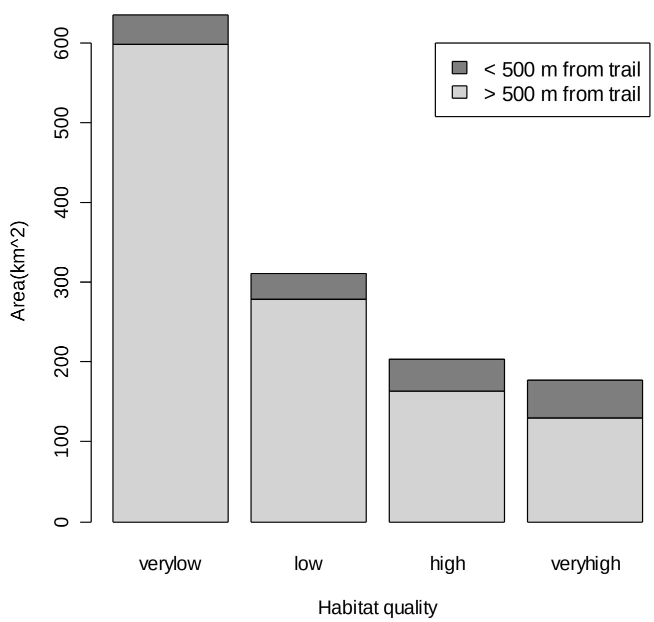


Figure 8. Amount of very low, low, high, and very high quality caribou habitat (km^2) within and beyond 500 m of trails in the in the alpine during summer. Twenty and 26% of high and very high quality habitat occurred within 500 m of hiking trails. Area estimates were calculated within the Tonquin, Maligne, and Banff caribou home ranges.

4.2 Wolves and trails

4.2.1 Wolf travel RSF Methods

A main objective of the South Jasper Woodland Caribou Project is to determine how roads and trails affect a caribou's risk of predation, especially during winter when ploughed roads and packed ski trails are thought to offer wolves with easy travel routes into caribou range (Brown et al. 1994). Several other studies have shown that wolves select roads and trails as travel routes, so long as levels of human use remain relatively low (Thurber et al. 1994; Musiani et al. 1998; James and Stuart-Smith 2000; Callaghan 2002; Whittington et al. 2004; Whittington et al. 2005). We hypothesized that wolves might more strongly select roads and trails as travel routes than for feeding and resting sites. Therefore, we defined wolf GPS locations as "travel" or "not travel" based on the distribution of step lengths and turn angles between successive GPS locations. We then selected travel locations and compared resources at those locations to random locations within each wolf's territory. We followed a similar model building and model validation approach to the caribou RSF models and used the same explanatory variables (Table 1). One difference in the modelling approach is that we used more random locations than travel locations. We first generated one random location for each wolf location. After filtering out travel locations, the relatively small number of remaining random locations poorly represented availability. Therefore, all random locations were used for each model. After building habitat related RSF models for wolf travel, we specifically tested for interactions between 'elevation' and both 'on trail' and 'on road' to determine whether wolves preferentially select for roads and trails at higher elevations when wolves are in caribou range.

We used a two-staged approach for defining GPS locations as "travel" or "not travel". First, we assumed that wolves traveled according to a correlated random walk (Turchin 1998) and that the distribution of step lengths and turn angles depended on whether wolves are feeding-resting or travelling. We used a Bayesian approach (Morales et al. 2004) to define changes in the distribution of step lengths (Weibull distribution) and turn angles (Wrapped Cauchy distribution). After calculating change-points in step length, we defined travel locations as GPS locations preceded and followed by long step lengths. Bayesian analyses were conducted using Python 2.3 and the package PyMC 0.84 (http://pymc.sourceforge.net) (Fonnesbeck 2005).

4.2.2 Wolf travel RSF Results

Change points in the distribution of step lengths and turn angles occurred at step lengths of 0.86 km (95% C.I. = 0.15 – 0.22) and 1.60 km (95% C.I. = 1.50 – 1.75). Steps greater than 1.6 km were considered 'long' and GPS locations preceded and followed by 'long' step lengths were defined as travel locations. Thirteen percent (n=544) of all wolf GPS locations were classified as travel locations.

Wolves preferentially selected roads and trails when traveling compared to feeding and resting (Figure 9). Therefore, using all GPS data would underestimate the effects of roads and trails on wolf travel routes. As expected, wolves selected roads and trails as travel routes in winter and spring. They selected trails as travel routes in summer and roads as travel routes in fall (Table 7). However, models for summer and fall were limited by smaller data sets (35 and 34 travel locations for summer and fall respectively). Interactions between elevation and trail further improved model performance in winter and spring (Figure 10), but not summer and fall. These interactions suggest that wolves more strongly selected trails at high elevations in winter and spring. One reason for the interaction is that snow depths increase with elevation and packed trails are thus energetically more efficient to travel routes at high elevations. In summer, forests in Jasper are relatively open and are not difficult for animals to travel through. Ninety-five percent of caribou locations occurred above 1885 m elevation and 58 (10.5%) of the 544 wolf travel locations occurred above this elevation. Of the 58 high elevation locations, seven (12%) occurred on trails and all seven occurred between October 28 and March 10.

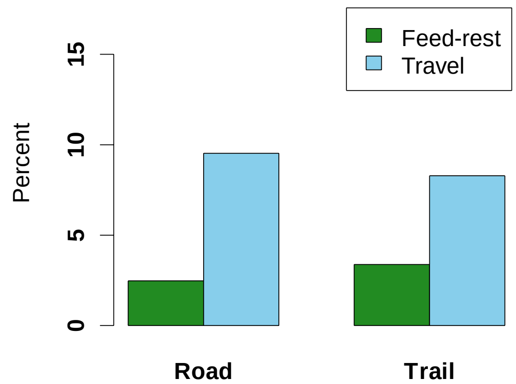


Figure 9. Percentage of wolf feed-resting and travelling locations that occurred within 50 m of roads and trails. Of the feed-rest locations, approximately 3 and 3% occurred on roads and trails respectively. Of the travel locations, approximately 10 and 9% occurred on roads and trails, respectively.

Table 3. β coefficients for models of resources selected by wolves when travelling.   "n.travel" indicates the number of wolf travel locations used within each model.

Variable	Winter	Spring	Summer	Fall
Intercept	-0.750	-0.730	-17.075	-3.485
elev	-2.044	-0.989	9.586	-0.508
$elev^2$			-2.495	
slope		-0.056	-0.117	-0.049
aspect.s	0.249			
tri.flat	0.814			
solar			0.244	
v.conifer.open	0.503		1.281	0.763
v.shrub	0.898			1.238
v.herb	0.900			1.352
v.barren				-8.556
riparian	0.671	0.470	0.554	
open		0.301		
road	1.526	1.305		1.177
trail	-1.186	-1.986	1.204	
elev * trail	1.361	1.627		
n.travel	235	240	35	34
ROC	0.850	0.773	0.928	0.819
k.fold mean	0.928	0.783	0.782	0.655
k.fold std	0.135	0.145	0.121	0.168

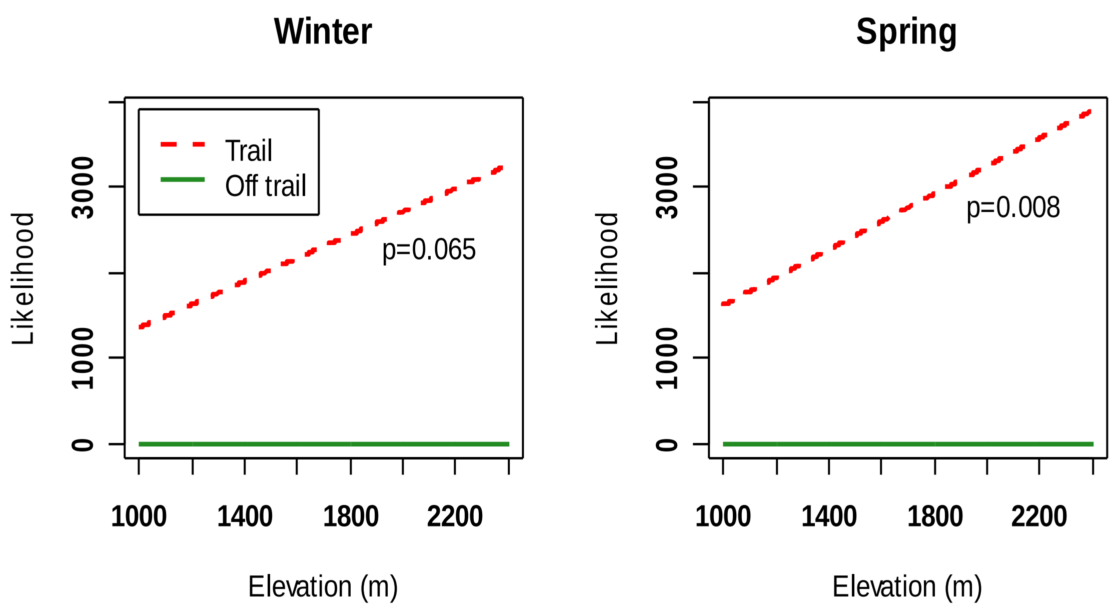


Figure 10. Likelihood of wolves travelling on and off trails versus elevation. Wolves exhibited stronger selection for trails at high elevations compared to low elevations in winter and spring.

4.3 Effects of people and wolves on caribou

Trails had the greatest effect on the distribution of caribou during the summer and fall and in the alpine. Most (80%) of the caribou had a negative association with trails during this time. During other times of the year, some but not all caribou had negative associations with trails. In most other areas of North America and Scandinavia, caribou avoided roads, trails, and seismic lines (Smith et al. 2000; Cameron et al. 1992; Wolfe et al. 2000; Dyer et al. 2001; Nellemann et al. 2001; Oberg 2001). However, in Gaspe region of Quebec, caribou were not displaced from important habitat but fed and rested less when people were nearby (Duchesne et al. 2000). Similarly, Caribou in Norway fled on average 370 m and 534 m when approached by skiers and snowmobiles respectively (Reimers et al. 2003).

Two mechanisms could explain why caribou had negative associations with trails. Caribou may have avoided the presence of people and/or may have avoided trails because of their higher risk of predation from wolves that select trails as travel routes. The first mechanism (caribou avoided people) is more likely for several reasons. Caribou had stronger negative associations to trails during the summer (June – August) and fall (September – November) when the largest number of people travel through caribou range. Compared to the subalpine, caribou had stronger negative associations to trails in the alpine where people and caribou can see further. Wolves showed stronger selection for roads and trails in the winter (December – February) and spring (March – May) compared to the summer and fall. Moreover, in summer wolves are not confined to trails by deep snows. That said, the relatively small number of wolf locations for summer and fall currently limits models of wolf movement and we do not have data to assess the risk of predation from grizzly bears and wolverine. In summary, these results suggest that caribou used areas near trails less than expected in summer and fall to avoid the presence of people more than minimize predation risk.

In winter and spring, wolves were more likely to select trails when travelling at higher elevations compared to low elevations. This suggests that packed trails may increase the risk of caribou predation. Wolves made relatively few trips into caribou range, yet the caribou population in Jasper is small enough that a few additional mortalities to adult female caribou may have large population consequences.

5. Vegetation sampling

Vegetation plots were sampled at caribou and random locations for three reasons. First, the plots were used to identify resources and foods selected by caribou at a microsite scale. Second, plots were used to understand the how fire and other factors affect the abundance and distribution of caribou foods. These first two objectives are the focus of a M.Sc. thesis by Landon Shepherd who plans to complete his thesis in fall 2005. The third objective of the vegetation plots was to contribute reference sites to data layers created from remote sensing by the University of Calgary (Dr. Greg McDermid) and the Canadian Forest Service. We contributed 94 and 253 plots from the summers of 2003 and 2004 respectively. Data layers created from remote sensing include land cover, canopy cover, species composition, and leaf area index. These layers were used as explanatory covariates for creating models of caribou and wolf resource selection.

6. Presentations

Table 4. Dates of presentations on the preliminary results of JNP's caribou study from April 2004 – March 2005 (excluding presentations to private businesses, parks staff, and recovery groups).

Date	Type	Audience	Location
2004-06-02	Public	Local interpreters, tour guides, and public.	Jasper, AB
2004-06-16	Public	Jasper public with external caribou experts.	Jasper, AB
2004-07-05	Public	Junior Forest Rangers	Hinton, AB
2004-09-18	Conference	Wildlife Society of North America	Calgary, AB
2004-09-22	Conference	Integrated research in mountainous areas	Banff, AB
2005-03-12	Conference	Wildlife Society of Alberta	Nisku, AB
2005-03-23	Public	Bow Valley Naturalists	Banff, AB

Table 5. Dates of caribou events for the public from April 2004 – March 2005..

Date	Event
2004-01-20	"Tracking caribou bus tour":
2004-02-28	"Caribou loppet":
2004-11-26	"Cakes for Caribou", community event organized by Friends of Jasper to raise awareness about caribou. An eating event where restaurants decorated and donated special chocolate deserts.
2005-01-22	Tracking Caribou bus tour, Jasper. Two large bus tours up the Maligne valley with park biologists to discuss caribou and wolf ecology and to search for wolves.
2005-02-26	Caribou Loppet, Jasper. A family oriented, non-competitive ski race and dinner for people from Jasper and surrounding areas.

7. Caribou Recovery

A recovery action plan was written for the Woodland caribou of south Jasper National Park (JNP), and approved in May of 2005. JNP staff, scientists and a variety of Jasper stakeholders collaborated on a committee from February 2004 – January 2005 to provide advice to Parks Canada regarding the recovery of the south Jasper caribou population. JNP staff prepared the recovery action plan based on the committee's advice. The recovery action plan identifies likely factors that are contributing to the caribou decline, and recommends recovery actions. A subset of the recommended actions were recommended for implementation (Phase 1), while other recommended actions will not be implemented unless the Phase 1 actions do not work. Most actions specified in the plan will be implemented by Parks Canada in the 2005-2005 fiscal year.

Recommended actions within the plan include:

- Protect or enhance high quality caribou habitat using fire management
- Dynamic speed limits and educational efforts to reduce the number of caribou-vehicle collisions
- Stepped-up enforcement/compliance on road speeds in caribou areas
- Eliminate use of road salt in caribou wintering areas or deter caribou from highways using lithium chloride.
- Restrict dogs to trails that are not in important caribou habitat
- Track-set ski routes into non-caribou habitat to offer skiers other options
- Minimize off-trail use in areas with high quality caribou habitat areas
- Prevent new trails from developing in areas of important caribou habitat
- Trail user education to promote personal choices that benefit caribou.
- Promote recreation use only to areas that don't have important seasonal caribou habitat
- Create guidelines for aircraft flying near high quality caribou habitat
- Investigate the use of fladry to inhibit wolf travel on packed trails in winter

The Species at Risk Act (SARA) requires that the competent minister or ministers prepare a recovery strategy for extirpated, endangered, or threatened species. SARA further stipulates that one or more action plans be prepared based on the recovery strategy. Strictly speaking, the South Jasper recovery action plan is neither a SARA recovery strategy, nor a SARA action plan, because the Alberta recovery strategy has not yet been finalized, and it is likely that the eventual action plan(s) will group the south JNP caribou with other populations. JNP has taken a collaborative, educational approach, therefore it is unlikely that items within the recovery action plan will raise objections by the provincial recovery team, however there may be additional recovery actions requested by provincial recovery team upon completion of the recovery strategy and action plan(s).

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Appendix

Table 6. Caribou RSF models for Subalpine. β-coefficients, SE's, Wald statistics, and p-values for covariates in the caribou RSF models.

Season	Variable	β	SE	Wald	p-value
Subalpine					
Summer	Intercept	-13.8207	1.240	-11.14	< 0.001
	elev	5.7441	0.545	10.53	< 0.001
	slope	-0.0304	0.007	-4.24	< 0.001
	aspect.w	0.4854	0.073	6.65	< 0.001
	curve120	0.0051	0.019	0.27	0.787
	dtree	-0.2916	0.172	-1.70	0.090
	v.herb	1.7911	0.325	5.52	< 0.001
	v.shrub	0.8526	0.271	3.15	0.002
	p_herb	0.0324	0.009	3.53	< 0.001
	fire150.	-0.6823	0.115	-5.94	< 0.001
	edge	0.4545	0.124	3.67	< 0.001
	trM	5.5572	0.895	6.21	< 0.001
Fall	Intercept	-19.9827	0.743	-26.90	< 0.001
	elev	10.2727	0.379	27.13	< 0.001
	slope	-0.0514	0.006	-9.11	< 0.001
	aspect.w	0.2481	0.058	4.30	< 0.001
	v.herb	0.9699	0.289	3.36	0.001
	v.barren	-1.6432	0.521	-3.15	0.002
Winter	Intercept	-19.6441	0.546	-35.95	< 0.001
	elev	8.3106	0.259	32.09	< 0.001
	tri.medium	0.3432	0.054	6.30	< 0.001
	v.barren	-0.6972	0.305	-2.29	0.022
	p_shrub	-0.0399	0.003	-13.30	< 0.001
	fire150.	0.5471	0.055	9.96	< 0.001
	edge	-0.3947	0.071	-5.59	< 0.001
	lai	0.6131	0.064	9.62	< 0.001
	lai2	-0.0656	0.009	-7.66	< 0.001
	trL	4.1040	0.348	11.78	< 0.001
Spring	Intercept	-15.9635	1.410	-11.32	< 0.001
	elev	3.7688	0.438	8.60	< 0.001
	curve120	0.1183	0.024	4.87	< 0.001
	tri.medium	0.7592	0.114	6.64	< 0.001
	v.herb	-8.3681	0.525	-15.93	< 0.001
	v.barren	-3.0402	1.088	-2.79	0.005
	p_shrub	-0.0954	0.008	-12.54	< 0.001
	edge	-1.1040	0.189	-5.85	< 0.001
	trL	6.2725	0.722	8.69	< 0.001
	trM	12.3014	2.134	5.76	< 0.001
Alpine					
Summer	Intercept	-9.1195	0.583	-15.63	< 0.001
	elev	1.4736	0.226	6.53	< 0.001
	slope	0.0446	0.012	3.81	< 0.001
	slope2	-0.0019	< 0.001	-7.10	< 0.001
	tri.flat	0.5351	0.128	4.18	< 0.001
	tri.medium	0.3036	0.079	3.85	< 0.001
	curve120	-0.0157	0.007	-2.20	0.028
	curve2	-0.0055	0.001	-5.56	< 0.001
	v.herb	0.8558	0.073	11.71	< 0.001
	v.shrub	1.0616	0.077	13.71	< 0.001
	p_herb	0.0432	0.002	20.98	< 0.001
	lai	0.0378	0.022	1.69	0.090
	dtree	-0.4174	0.053	-7.91	< 0.001
	trM	8.9139	0.501	17.78	< 0.001
Fall	Intercept	-12.6400	0.672	-18.81	< 0.001
	elev	2.6390	0.266	9.93	< 0.001
	slope	0.0146	0.011	1.30	0.192
	slope2	-< 0.0019	< 0.001	-3.66	< 0.001
	aspect.w	0.3381	0.038	8.85	< 0.001
	tri.flat	0.9595	0.128	7.51	< 0.001
	tri.medium	0.6148	0.083	7.37	< 0.001
	curve120	-0.0277	0.007	-3.94	< 0.001
	curve2	-0.0020	0.001	-2.18	0.029
	v.herb	1.4930	0.073	20.36	< 0.001
	v.shrub	1.5070	0.082	18.49	< 0.001
	p_herb	0.0371	0.002	20.54	< 0.001
	p_shrub	0.0248	0.002	13.34	< 0.001
	dtree	-0.5998	0.056	-10.72	< 0.001
	trL	5.6590	0.392	14.43	< 0.001
	trM	3.0450	0.269	11.30	< 0.001
Winter	Intercept	-3.0637	0.516	-5.94	< 0.001
	slope	0.0569	0.015	3.76	< 0.001
	slope2	-0.0017	< 0.001	-5.33	< 0.001
	tri.flat	-0.3717	0.201	-1.85	0.065
	tri.medium	0.5339	0.109	4.88	< 0.001
	curve120	0.0546	0.009	6.14	< 0.001
	curve2	-0.0072	0.001	-5.32	< 0.001
	v.herb	1.0898	0.096	11.39	< 0.001
	v.shrub	0.7015	0.109	6.46	< 0.001
	p_shrub	-0.0096	0.003	-2.90	0.004
	dtree	-1.6523	0.100	-16.51	< 0.001
	trL	6.3120	0.914	6.90	< 0.001
Spring	Intercept	-7.4668	0.549	-13.59	< 0.001
	slope	0.0954	0.014	6.78	< 0.001
	slope2	-0.0032	< 0.001	-9.02	< 0.001
	tri.medium	0.5219	0.074	7.08	< 0.001
	curve120	0.0305	0.007	4.28	< 0.001
	v.herb	0.9931	0.082	12.10	< 0.001
	v.shrub	0.5152	0.083	6.19	< 0.001
	dtree	-1.1362	0.081	-14.06	< 0.001
	trL	5.5947	0.584	9.57	< 0.001
	trM	8.7855	0.882	9.97	< 0.001

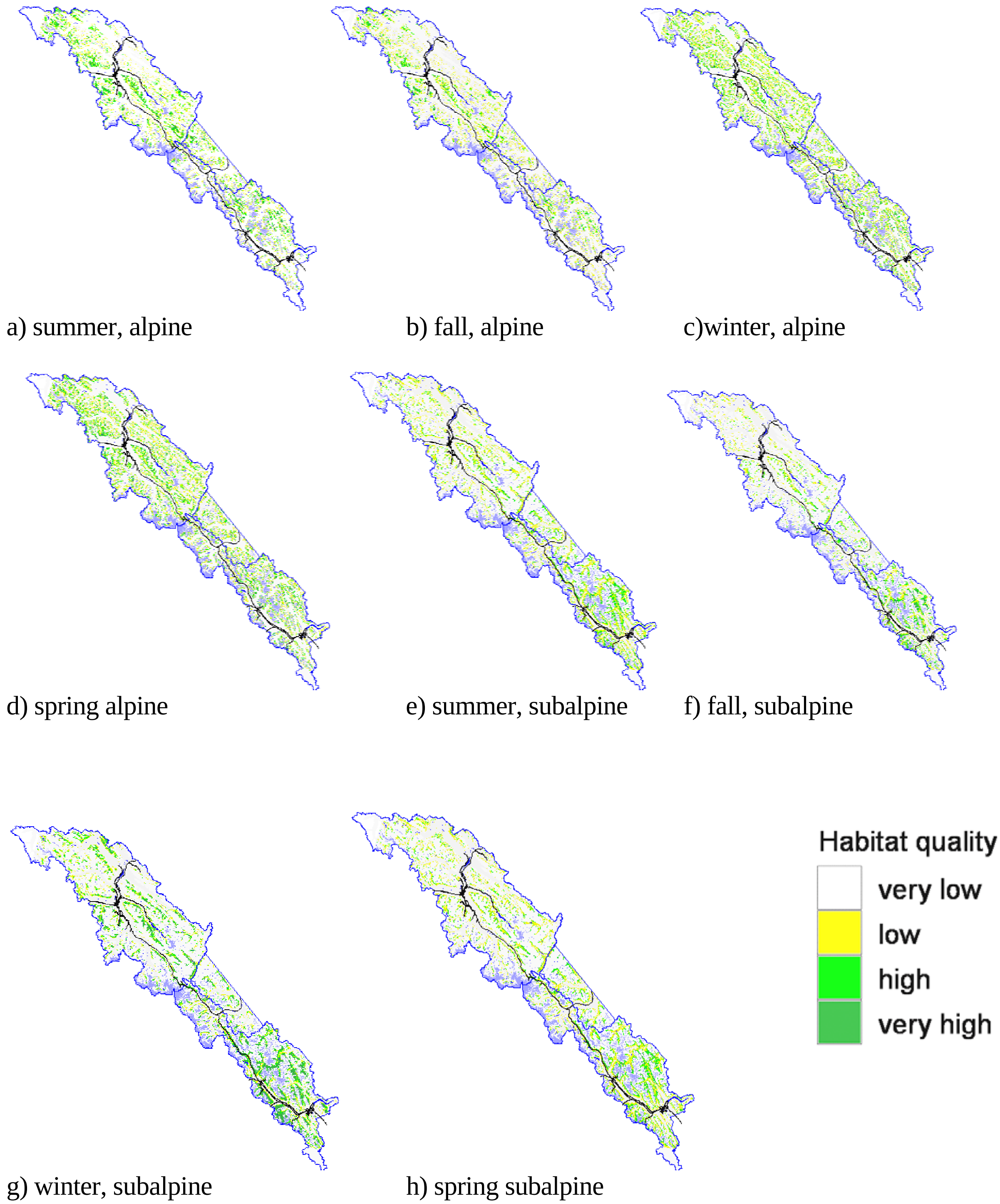
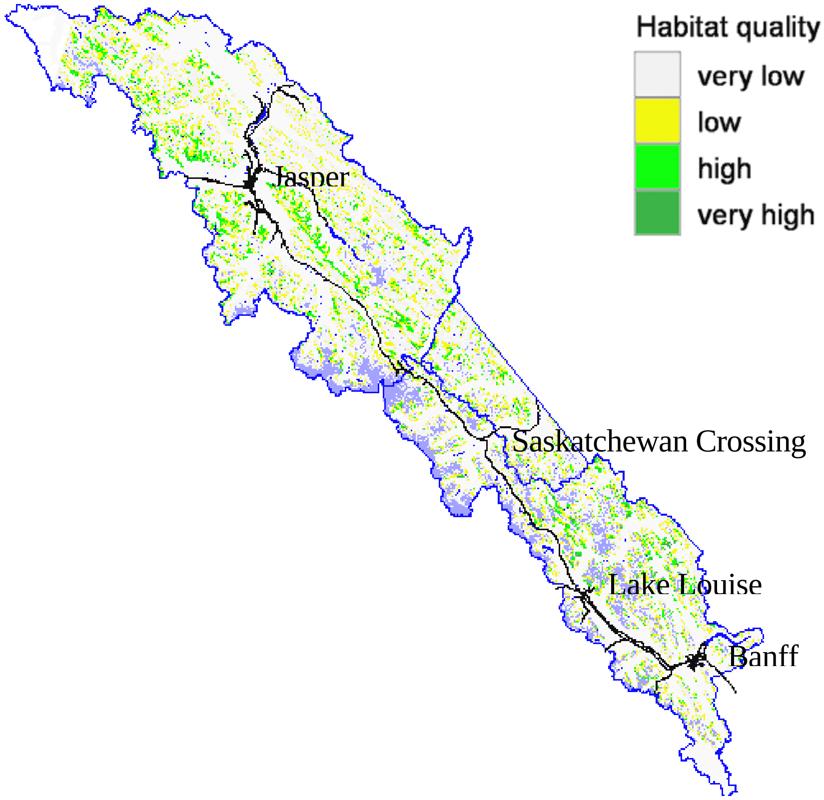
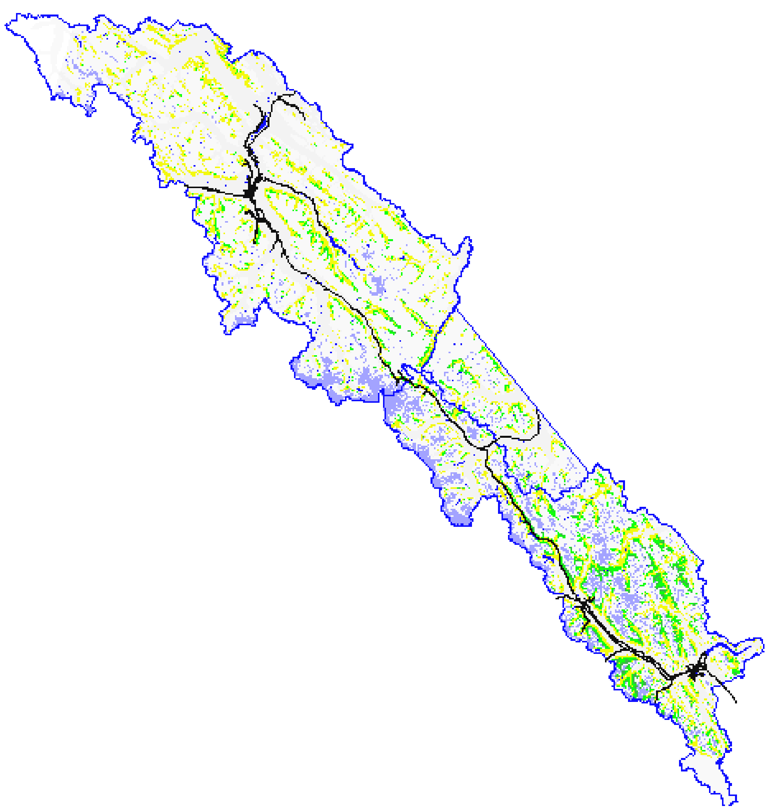


Figure 11. Predictive maps of caribou occurrence by season and ecoregion. Separate models were created for the alpine and subalpine because caribou likely select different foods in each area. The relative importance of alpine versus subalpine depended on season and is not reflected in these maps. In summer and fall, 80 and 75% of caribou locations occurred in the alpine. In winter and spring, 33 and 51% of the locations occurred in the alpine.



a) Alpine, averaged across seasons



b) Subalpine, averaged across seasons.

Figure 12. Predictive maps of caribou occurrence for the a) alpine and b) subalpine ecoregions. Maps were generated by averaging predictive values across seasons.

Table 7. Resources selected by wolves when travelling in winter, spring, summer, and fall. β-coefficients, SE's, Wald statistics, and robust p-values are given for each covariate.

Season	Variable	β	SE	Wald	p-value
Winter	Intercept	-0.750	0.379	-1.98	0.048
	elev	-2.044	0.219	-9.31	0.000
	aspect.s	0.249	0.132	1.89	0.059
	tri.flat	0.814	0.174	4.67	0.000
	v.conifer.open	0.503	0.201	2.50	0.013
	v.shrub	0.898	0.230	3.91	0.000
	v.herb	0.900	0.286	3.15	0.002
	riparian	0.671	0.156	4.30	0.000
	trail	-1.186	0.976	-1.22	0.224
	road	1.526	0.275	5.55	0.000
	elev * trail	1.361	0.736	1.85	0.065
Spring	Intercept	-0.730	0.257	-2.85	0.004
	elev	-0.989	0.192	-5.15	0.000
	slope	-0.056	0.009	-6.31	0.000
	riparian	0.470	0.150	3.14	0.002
	open	0.301	0.158	1.90	0.057
	road	1.305	0.325	4.01	0.000
	trail	-1.986	0.919	-2.16	0.031
	elev * trail	1.627	0.615	2.65	0.008
Summer	Intercept	-17.075	3.726	-4.58	0.000
	slope	-0.117	0.023	-5.15	0.000
	elev	9.586	4.429	2.16	0.031
	elev2	-2.495	1.326	-1.88	0.060
	riparian	0.554	0.377	1.47	0.142
	solar	0.244	0.029	8.36	0.000
	v.conifer.open	1.281	0.566	2.26	0.024
	trail	1.204	0.594	2.03	0.043
Fall	Intercept	-3.485	0.865	-4.03	0.000
	elev	-0.508	0.551	-0.92	0.357
	slope	-0.049	0.017	-2.93	0.003
	v.conifer.open	0.763	0.480	1.59	0.111
	v.shrub	1.238	0.498	2.49	0.013
	v.herb	1.352	0.587	2.30	0.021
	v.barren	-8.556	0.309	-27.73	0.000
	road	1.177	0.735	1.60	0.109