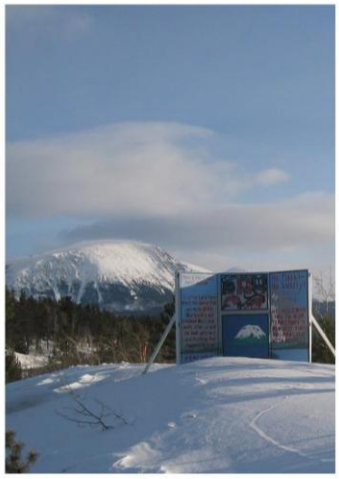

Atlin Northern Mountain Caribou Habitat Modeling and Cumulative Human Impact Assessment

Report prepared for

The Taku River Tlingit First Nation

by Jean Polfus
Kimberly Heinemeyer
Mark Hebblewhite

June 2010

ATLIN NORTHERN MOUNTAIN CARIBOU HABITAT MODELING AND CUMULATIVE HUMAN IMPACT ASSESSMENT

JUNE 16, 2010

REPORT PREPARED FOR

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DISCLAMER

This report contains data from academic research directed by the University of Montana that was developed as a graduate student thesis and is intended for scientific publication.

COVER PHOTO CREDITS

Jean Polfus (top left, TRTFN Territory sign, bottom left, bottom middle, middle), Wibke Peters (bottom right), Kevin Cannaday (caribou on road). Drawing of caribou by Jean Polfus.

SUGGESTED CITATION

Polfus, J.L., K.S. Heinemeyer, M. Hebblewhite. 2010. Atlin Northern Mountain Caribou Habitat Modeling and Cumulative Human Impact Assessment. Final Report submitted to the Taku River Tlingit First Nation, June, 2010. Available at: http://www.roundriver.org/index.php?option=com_content&view=article&id=67&Itemid=57

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FUNDING

Funding for this project was provided by the Habitat Stewardship Program for Species at Risk of Environment Canada, the Taku River Tlingit First Nation, Round River Conservation Studies, and the University of Montana.

ACKNOWLEDGEMENTS

The long-term vision of the Taku River Tlingit First Nation (TRTFN) made this project possible by identifying the need for sustainable management of the wildlife and resources in their traditional territory. Many TRTFN members contributed their ecological knowledge and expertise including Jackie Williams, Bryan Jack, Andrew Williams, Terry Jack, Harry Carlick, Richard Carlick, Greta Thorlakson, Douglas Jack, and Rickard Johnson. Field research that contributed to this report has benefitted from the assistance of Jerry Jack and Phillip Tizya.

The partnership between the TRTFN and Round River Conservation Studies (RRCS) facilitated the development of funding proposals, project management, reporting and implementation, and development of project partnerships. We thank the dedicated RRCS staff and students who assisted with logistics, field work, interviews, and habitat modeling; Doug Milek, Heidi Larsen, Rick Tingey, Chris Lockhart, Claire Polfus, Susie Dain-Owens, Leah Larsen, Jeff Muntifering, Kevin Cannaday, Basilia Andoroone Shivute, Drew Chambers, Megan Mitchell, Matt Stone, Maggie Harris, Jake Robert Claro, Rebecca Guiao, Natalie Coleman, Blakeley Adkins, Carol Drysdale, and Eli Rosenfeld. We are indebted to Dennis Sizemore who has consistently and generously supported Round River's participation in this work.

This project was made possible through collaboration with the University of Montana. The Hebblewhite lab provided assistance in development, analysis, and editing. In particular we thank Nick DeCesare, Hugh Robinson, Lacey Greene, Shawn Cleveland, Clay Miller and Wibke Peters. Jeanne Franz made navigating the administration at the University of Montana possible. Additionally, Michael Mitchell and Paul Krausman assisted with organization, project design advice and provided helpful revisions.

Important support from the British Columbia Ministry of Environment aided in the completion of this project. Specifically, Karen Diemert, Mark Williams and Rick Marshall provided valuable animal location data, advice on sampling efforts, and assistance with project logistics. Norm Maclean helped with data collection and management. Don Reid, of the Wildlife Conservation Society, generously provided vegetation data to assist in the land cover classification. Collaborations with Greg McDermid and Adam McLane at the University of Calgary contributed essential assistance through the development of an updated landcover classification.

We genuinely appreciate the valuable contributions of all the others who volunteered their time to assist with this study.Finally, we remain in awe of the caribou, whom we have so much more to learn from. Gunalcheesh, Thank You.

EXECUTIVE SUMMARY

Woodland caribou (*Rangifer tarandus caribou*) are distributed throughout the boreal forest of Canada and require large expanses of relatively undeveloped landscapes to persist. Due to increasing levels of human infrastructure development and declines throughout their range, woodland caribou have been federally listed under the Canadian Species at Risk Act (SARA). The northern mountain woodland caribou ecotype occurs in local populations throughout the Yukon, Northwest Territories and northwestern British Columbia (BC). Recent population declines caused by human overharvest, habitat loss and fragmentation from forestry and energy development, human-induced changes to predator-prey communities, and proliferation of road and snowmobile networks prompted federal managers to list northern mountain woodland caribou as a *species of special concern* under SARA in 2004.

The Atlin herd of northern mountain woodland caribou occurs in the territory of the Taku River Tlingit First Nation (TRTFN). Recent population modeling has indicated the herd has low productivity and is likely declining. There is a growing need to understand how the cumulative effects of past and current human development, and potential future development, affect habitat selection and population status of the Atlin herd. Mitigating cumulative effects of existing and proposed future human developments requires a quantitative understanding of habitat selection. The project objective was to use an innovative combination of habitat modeling approaches to determine the effect of cumulative human developments. To support this effort, we collaborated with the University of Calgary to develop an updated landcover classification for the range of the Atlin herd based on satellite imagery. The landcover classification improved on previous forest cover land models, and the new product was used in the development of seasonal caribou habitat models.

To understand the cumulative impacts of current and potential future human development on caribou habitat we developed summer and winter resource selection function (RSF) models at 2 spatial scales with data from 10 caribou collared with global positioning system (GPS) units provided by the BC Ministry of the Environment. Resource selection functions use a statistical framework to quantify habitat relationships by comparing use of spatial resources relative to their availability. When an animal uses a resource in the landscape disproportionate to its availability, selection is assumed. When use is less than availability, the model predicts avoidance of that resource. Avoidance is defined as a reduction in use compared to what would be expected based on availability. We assessed cumulative human impacts by estimating the zone of influence (ZOI) avoided by caribou around several types of human development (roads, mines, cabins and hunting camps, and the town of Atlin).

Results of the RSF analyses indicate that caribou avoided multiple types of human development. We also found that selection decisions were made by caribou in a hierarchical fashion with increased sensitivity to human developments at the larger scale.

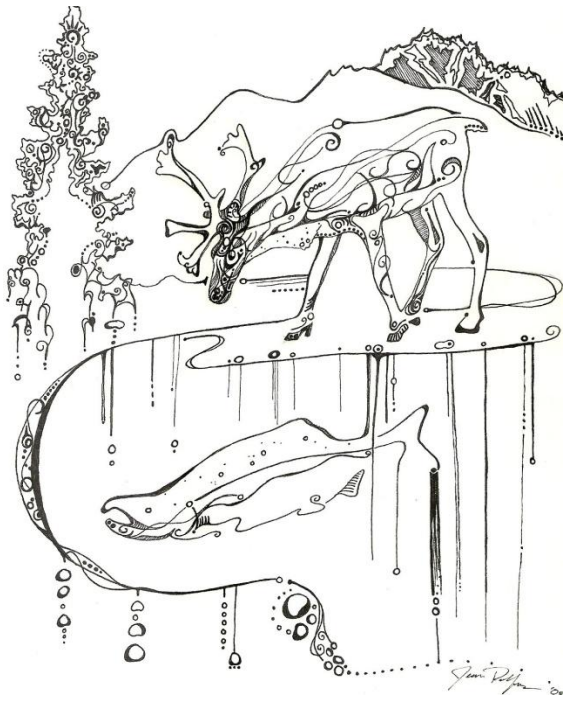
At the larger landscape scale, we found caribou avoided high use (plowed/paved) roads by 2 km and low use roads by 1 km in both summer and winter. Caribou avoided the town of Atlin by 9 km in winter and by 3 km in summer. Significant avoidance of mines (2 km) and cabins and hunting camps (1.5 km) was only observed during summer, potentially because the level of human activity on the landscape increases significantly in summer due to ease of access to the road and ATV networks and seasonally active placer mines.

We evaluated the cumulative impacts of human development on caribou by comparing estimates of potential habitat (defined as the habitat available to caribou when not constrained by avoidance of human developments) and realized habitat (current habitat use estimated from RSFs). The relationship between potential and realized habitat can be used to quantify the reduction in habitat due to the indirect avoidance of existing human developments. We determined that 8% of high quality winter habitat and 2% of high quality summer habitat has been alienated due to indirect avoidance of existing human developments. For example, areas surrounding the town of Atlin and high use roads contain high quality winter habitat that is used less than expected under current human development.

Based on the RSF habitat model and the ZOI results, we have developed an approach to predict the potential effects of future development on caribou habitat quality. To exemplify this approach, we assessed the potential impact of roads associated with the proposed construction of the Adanac molybdenum mine and the Tulsequah multi-metal mine. Our results predict that the roads associated with these proposed development would potentially alienated 31.4 km2 of high quality winter habitat (1% of total high quality winter habitat) and 7.8 km^2 of high quality summer habitat (0.2% of high quality summer habitat) through indirect habitat loss. These predictions are likely conservative estimates of the amount of habitat lost for a number of reasons detailed in the report. The cumulative effect of current and potential indirect habitat loss could result in further declines of the herd.

Previous work in this region has highlighted the importance of using the traditional ecological knowledge (TEK) of the TRTFN to aid wildlife management decisions. A robust combination of TEK and Western science approaches to caribou habitat modeling and conservation planning has the potential to improve efficiency of management decisions and enhance the validity and robustness of ecological inferences. We examined the strengths and weakness of Western scientific and TEK approaches to modeling caribou habitat. Our objectives were to test the ability of TEK and Western science habitat models to spatially predict the occurrence of caribou in the study area, using observations from very high frequency (VHF) and GPS collared caribou. Additionally, to gain insights into differences between the models, we compared the predictions of TEK and Western science habitat modeling approaches.

Habitat suitability index (HSI) models were generated from TEK interviews with TRTFN members. Habitat suitability index models predict habitat quality using expert opinion such as TEK. We found that both TEK-based HSI models and RSF models were robust predictors of independent caribou locations. The direct comparison of habitat ranks between the 2 types of models showed some spatial discrepancies, but both approaches successfully predicted caribou habitat quality. Underlying differences appeared to be primarily a result of RSF models predicting more high quality habitat than TEK models. This could have been a result of how model habitat ranks were classified or differences between the resource covariates incorporated in each model. Our results indicate TEK-based habitat models can be a useful approach to predicting caribou habitats; this finding is particularly important in northern ecosystems that frequently lack long-term Western science data to inform management decisions. Combining TEK-based HSI models with cumulative effects assessments will support management and recovery goals for woodland caribou across northern Canada.



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Chapter 2.

Appendix A.

CHAPTER 1: INTRODUCTION

As the human population continues to increase, encroachment on undeveloped ecosystems is inevitable (McKinney 2002, Foley et al. 2005). The accelerating rate of habitat loss is the primary cause of wildlife population decline and extinction (Fahrig 1997, Myers et al. 2000, Brooks et al. 2002). Conservation efforts are often reactionary and focus on declining species that have decreased survival and reproduction due to habitat deterioration and loss (Ludwig et al. 1993). However, restoring degraded habitat, by increasing its quality to support survival and reproduction of a species, is rarely effective (Hall et al. 1997, Sinclair et al. 2006). Therefore, focusing conservation efforts on areas where human influence is low may be the most efficient way of protecting the world's remaining biodiversity (Sanderson et al. 2002). In Canada, for example, relatively large tracts of wilderness endure, especially in the boreal forest. However, habitat loss due to increasing levels of development and resource extraction has resulted in over 565 species being listed as threatened or endangered under Canada's Species at Risk Act (SARA, Kerr and Deguise 2004). Proactively protecting threatened species in the boreal forest before they become endangered allows for the conservation of a wide range of biodiversity and at the same time minimizing conflicts (Abbitt et al. 2000).

Woodland caribou (*Rangifer tarandus caribou*) are distributed throughout the extent of the boreal forest in Canada and require large expanses of relatively undeveloped landscapes to persist (Apps and McLellan 2006). Additionally, woodland caribou are valued culturally by many Canadians and First Nations, making them a model umbrella species for the boreal forest (Simberloff 1998, Hummel and Ray 2008). Due to increasing levels of human infrastructure development and declines throughout their range (Vors and Boyce 2009), woodland caribou have been federally listed under SARA. The level of risk designated by SARA varies between woodland caribou ecotypes. Ecotypes are defined by adaptations to different environments that require particular movements and feeding behavior (Bergerud 1978, Heard and Vagt 1998, Spalding 2000). In the southern portions of Alberta, British Columbia (BC) and the boreal forests of Canada, the southern mountain and boreal ecotypes of woodland caribou are listed as threatened due to habitat loss associated with oil, gas, mining, and forestry extraction (Wittmer et al. 2005b, Apps

and McLellan 2006, Schaefer and Mahoney 2007). Human development has altered predator-prey relationships causing declines and recently, extirpation of some herds (Wittmer et al. 2005c, Hebblewhite et al. 2010). By providing young seral forests that are preferred by moose *(Alces alces)* and wolves *(Canis lupus)*, human activities increase caribou vulnerability to predation through the mechanism of apparent competition (James and Stuart-Smith 2000, James et al. 2004, DeCesare et al. 2010).

The northern mountain woodland caribou ecotype occurs in local populations throughout the Yukon, Northwest Territories and northwestern BC. Human development in the northern population's range has not impacted caribou habitat to the same extent as it has in southern regions of Canada. Thus, northern mountain woodland caribou provide a conservation opportunity to proactively identify and protect habitat before habitat loss negatively affects populations. However, even in remote regions inhabited by northern mountain woodland caribou, hunter overharvest, habitat loss and fragmentation from forestry and energy development, human-induced changes to predator-prey communities and proliferation of road and snowmobile networks have, to varying degrees, contributed to population declines. These declines prompted federal managers to list northern mountain woodland caribou as a *species of special concern* in 2004 under SARA (Kinley and Apps 2001, Thomas and Gray 2002, Seip et al. 2007, Northern Mountain Caribou Management Planning Team 2009).

The importance of caribou in the culture and natural resource use by aboriginal people makes First Nation involvement an important consideration in caribou recovery or management planning (Manseau et al. 2005, Houde 2007). The range of northern mountain woodland caribou includes the traditional territory boundaries of 33 First Nations (Northern Mountain Caribou Management Planning Team 2009). Federal and provincial guidelines require that planning for listed species take into consideration co-management agreements between First Nations and provincial governments which can be complicated by unresolved land claims where treaties were never established.

In the far northwestern corner of BC, monitoring indicates that the Atlin northern mountain woodland caribou herd has recently been stable or decreasing (Farnell et al. 1998, Heard and Vagt 1998, Heinemeyer 2006). Potential population declines are thought to be due to a combination of habitat loss associated with increased road access,

increasing snowmobile use, predation, recreation, industry and mineral exploration and development (Northern Mountain Caribou Management Planning Team 2009, Taku River First Nation and British Columbia 2010). The Atlin herd occurs within the traditional territory of the Taku River Tlingit First Nation (TRTFN), whose members have a long history of sustainable governance and stewardship of their lands and resources and value the Atlin caribou herd as a culturally important source of meat and other products (Taku River Tlingit First Nation 2003). The TRTFN has a deep sense of obligation to their lands and wildlife. In the spring of 2007, the TRTFN and the government of BC agreed to enter into joint land-use and wildlife management planning in the Atlin/Taku (TRTFN/BC 2008). One of the focal species for this joint wildlife management planning is northern mountain woodland caribou.

Negotiating the complex political dynamics that surround caribou conservation often requires collaborative management. Agreements to share responsibility for land and resources between government and local resource users have the potential to increase the validity of ecological insights, aid in effective management, and enhance equity in the decision-making by empowering local people (Houde 2007). In the Canadian north, First Nation members often possess valuable information about their environment. This knowledge is often termed traditional ecological knowledge (TEK), and is developed through a deep historical continuity in resource use in a particular place (Berkes 1999). In this context, traditional does not specifically represent only oral history, but rather information about the local ecology that has been acquired through direct experiences in particular environments and shared within a community (Davis and Ruddle 2010). Combining TEK with Western science methods that arose from a European philosophical and cultural context (Pierotti and Wildcat 2000), has the potential to bring new values, ideas, and information to resources management. However, many ethical and philosophical issues surround the incorporation and validation of TEK with Western science (Brook and McLachlan 2005). The distillation of TEK into components that conform to a specific category of Western science (such as caribou habitat relationships) can, at times, fail to acknowledge the broader cultural context from which TEK was shaped (Nadasdy 1999). Some have argued that the process of validating TEK can cause a loss of integrity (Nadasdy 1999, Davis and Ruddle 2010), which can lead to the

marginalization of aboriginal communities by securing the management authority of Western science (Nadasdy 1999). Yet, if the goal is to improve the conservation and sustainable management of resources and wildlife, then respectful and honest comparisons of TEK and Western science are needed to assess the appropriate role for TEK as a management tool (Davis and Ruddle 2010). Through co-management, TEK has the potential to provide alternative insights into conservation issues, natural resource use, and political and societal pressures that may not be acknowledged or emphasized in Western science (Pierotti and Wildcat 2000). Furthermore, TEK has the potential to compliment and provide an alternative to Western science, particularly where investment in research has not been undertaken.

CHAPTER 2: NORTHERN WOODLAND CARIBOU HABITAT SELECTION AND CUMULATIVE EFFECTS ASSESSMENT IN NORTHERN BRITISH COLUMBIA

INTRODUCTION

Caribou and reindeer (*Rangifer tarandus*) are sensitive to anthropogenic activities and human infrastructure and are in decline worldwide (Spalding 2000, Vors and Boyce 2009). Humans directly affect *Rangifer* through habitat loss (Weir et al. 2007), hunting mortality (Bergerud 1967, Kinley and Apps 2001), increased energetic costs (Bradshaw et al. 1998, Freeman 2008), and barriers to movement (Curatolo and Murphy 1986, Dyer et al. 2002). In addition, avoidance of areas close to human infrastructure developments, such as roads, mines, cabins, and towns, may also lead to indirect habitat loss and is a growing threat to caribou and reindeer populations (Vistnes and Nellemann 2008, Vors and Boyce 2009). Studies have documented that *Rangifer* avoid areas near roads, seismic lines, oil well sites, human settlements, tourist resorts and cabins, power lines, hydroelectric developments, mine sites, logging clearcuts, and snowmobile activity (Dyer et al. 2001, Nellemann et al. 2003, Schaefer and Mahoney 2007, Seip et al. 2007). Across southern Canada, southern mountain and boreal woodland caribou (*Rangifer tarandus caribou*) populations are threatened by indirect habitat loss associated with oil and gas, mining, forestry extraction (Wittmer et al. 2005b, Apps and McLellan 2006, Schaefer and Mahoney 2007), and the indirect effects of apparent competition. Apparent competition is a result of landcover alteration that changes predator-prey relationships by providing young seral forests that are preferred by moose *(Alces alces)* and wolves *(Canis lupus)* that indirectly increases caribou vulnerability to predation (James and Stuart-Smith 2000, James et al. 2004, DeCesare et al. 2010). While the indirect effects of habitat loss from different development types may be individually inconsequential, their cumulative impact has the potential to significantly affect caribou over time (Spalding 1994, Jeffrey and Duinker 2000, Scott 2007).

Mitigating cumulative effects of existing and proposed future human developments requires a quantitative understanding of habitat selection by animals

(Turner et al. 2004, Hirzel and Le Ley 2008). Habitat is important because it constitutes the resources and environmental conditions in an area that determine the survival and reproduction of a given organism (Hall et al. 1997, Sinclair et al. 2006). Selection is the process by which an animal chooses resources and conditions disproportionately to their availability (Johnson 1980). Habitat selection is assumed to be positively related to fitness because an individual's habitat preferences are shaped over evolutionary time to lead to increased survival and reproductive success (Railsback et al. 2003, McLoughlin et al. 2006), though this may not always be the case, especially for species responding to novel human disturbance (Garshelis 2000, Robertson and Hutto 2006). Resource selection functions (RSF) use a statistical framework to quantify habitat relationships by comparing use of spatial resources relative to their availability (Manly et al. 2002). These models integrate multiple environmental variables, including human impacts, and are easily integrated into spatially-explicit geographic information systems (GIS). As a result, RSFs are powerful tools for predicting animal occurrence in resource management, cumulative effects assessments (CEA) and population viability analysis (Boyce and McDonald 1999).

The objectives of this study were to understand the cumulative impacts of current and potential future human development on caribou habitat through development of seasonal RSF models at two spatial scales. We focused on the northern mountain ecotype of woodland caribou that occurs throughout the Yukon, Northwest Territories and northwestern BC. This ecotype was listed as a species of special concern in 2004 by the Species at Risk Act (SARA). In northwestern BC, the Atlin herd has maintained a stable or decreasing population in recent years (Farnell et al. 1998, Heard and Vagt 1998, Heinemeyer 2006, Taku River First Nation and British Columbia 2010). There is a growing need to understand how the cumulative effects of past and current human development, and potential mining, affect habitat selection and population status of the Atlin herd.

Ungulates respond to their environment in a hierarchical fashion across spatial scales (Johnson 1980, Senft et al. 1987, Bowyer and Kie 2006). Caribou may select habitat to reduce predation at coarser (landscape) scales and to maximize forage at finer (home range) scales (Schaefer and Pruitt 1991, Rettie and Messier 2000, Johnson et al.

2001). Recent studies have also shown that cumulative effects of human developments can manifest at multiple scales (Houle et al. 2010). Therefore, we focused on caribou habitat selection at Johnson's (1980) second-order (landscape) scale and third-order (within home range) scale during both winter and summer. Winter has been thought to be the most limiting season for ungulates due to increased energetic costs of gestation for females (Pekins et al. 1998), movement in snow (Parker et al. 1984, Fancy and White 1987), and starvation due to poor winter nutrition (Gates et al. 1986, Wittmer et al. 2005c). But recent work has also shown summer habitat to be critical because of the importance of summer nutrition to ungulate population dynamics (Parker 2003, Cook et al. 2004). In winter, northern mountain woodland caribou forage on terrestrial lichen in forest stands and in alpine windswept areas (Johnson et al. 2000, Gustine and Parker 2008) and primarily forage on herbaceous vegetation and lichen in alpine environments in summer (Oosenbrug and Theberge 1980, Ion and Kershaw 1989). Therefore, we hypothesized that within the second-order scale, caribou would avoid human development while selecting resources such as pine/lichen stands in winter and alpine areas in summer. At the third-order scale (within home range) we predicted that forage selection would drive resource selection in both seasons and that human developments would have less of an effect on selection because of avoidance at the larger scale (Rettie and Messier 2000).

Understanding the interactions between resource selection and past, present, and future human development is crucial to the management of threatened and endangered species (Jeffrey and Duinker 2000, Vistnes and Nellemann 2008). The effects of human development can be complicated when multiple human developments exist in proximity because the aggregate impacts exceed the sum of the individual effects (Spaling and Smit 1993). Furthermore, animal responses to different types of human development can vary (Nellemann et al. 2000, Hood and Parker 2001, 2001). We tested the cumulative impact of human development on caribou resource selection and used our models to predict the amount of historic indirect habitat loss due to existing human developments as well as the impact of future development scenarios. We expected human development to decrease the amount of habitat available to caribou through indirect habitat loss. Realized habitat can be considered the current habitat available to caribou when avoidance of human

developments is accounted for (Austin et al. 1990, Guisan and Zimmermann 2000, Hirzel and Le Ley 2008). In contrast, in this context, potential habitat can be considered habitat without the effects of human development (Pulliam 2000, Soberón 2007, Hirzel and Le Ley 2008). Thus, we removed the existing effects of human development within our habitat models to predict potential habitat (Figure 2-1). Finally, once the cumulative impact of past and present human development was understood, we evaluating future development scenarios in habitat models to assess the effects of potential new development (Schumaker et al. 2004).

METHODS

STUDY AREA

This study focused on an 11,594 km^2 area within the Atlin northern mountain woodland caribou herd's home range east of Atlin Lake to Teslin Lake along the Yukon-BC border (Figure 2-2). Our study area occurred in the Skeena region of northwest BC within the boreal mountains and plateaus ecoregion (Environment Canada 2005). Elevations range from 660 to 2,000 m. The climate is typified by long, cold winters and short, warm summers. The mean summer temperature is 10°C and the winter mean is -15°C (Environment Canada 2005). Annual precipitation in Atlin is approximately 33 cm (MacKinnnon et al. 1999) resulting in an average late winter snow depth of 50 cm, that is low compared to other regions of northern BC (http://www.climate.weatheroffice.ec.gc.ca/climateData/canada_e.html). Low to mid-elevation boreal forests include open coniferous and mixedwood stands dominated by lodgepole pine (*Pinus contorta latifolia*), subalpine fir (*Abies lasiocarpa*) and white spruce (*Picea glauca*). Deciduous stands of trembling aspen (*Populus tremuloides*), black cottonwood (*Populus balsamifera trichocarpa*), alder (*Alnus tenuifolia*) and willow (*Salix* spp.) occupy valley bottoms. Other ungulates include moose, mountain goats (*Oreamnos americanu*) and Stone's sheep (*Ovis dalli stonei)*. The large mammal predator community consists of grizzly bears (*Ursus arctos*), black bears (*Ursus americanus*), wolverines (*Gulo gulo*), wolves and lynx (*Lynx canadensis*).

The study area composed approximately a quarter of the traditional territory of the Taku River Tlingit First Nation (TRTFN). During the Klondike gold rush of 1898, the

Tlingit village of Atlin (59° 35' N, 133° 40' W) was populated by over 10,000 miners who left a legacy of trails and abandoned mines. Today there are approximately 350 residents in Atlin including roughly 130 TRTFN members that reside in town and the nearby Indian Reserve at Five Mile Point (http://www.gov.bc.ca/arr/). One road (HWY-7) connects Atlin to the Alaska Highway and the city of Whitehorse in the Yukon Territory. Paved roads extend out from the town (98.1 km) and the total road density within 10 km of Atlin is 0.53 $km \bullet km^{-2}$. Throughout the entire study area, unimproved gravel and dirt roads (398.4 km) and ATV trail systems (739.3 km) connect local logging operations and placer and hardrock mines (n~94) for an overall road density of 0.11 $km \bullet km^{-2}$. Two large-scale mining operations have recently been proposed in the study area. Redfern Resources Ltd. planned to re-open a controversial multi-metal mine site on the Tulsequah River, 50 km south of the study area. Initially, a 160 km access road from Atlin to the mine site was proposed (www.redcorp-ventures.com). In the center of the study area, the Adanac Molybdenum Corporation proposed to develop an open pit molybdenum mine site on Ruby Creek, 20 km northeast of Atlin (Canadian Environmental Assessment Agency 2009). Both projects have received a number of the required government permits and approvals, but potential development of the properties is unknown. Still, due to the high mineral potential in the region, it is foreseeable that these or other mining developments may occur in the future.

ANIMAL CAPTURE

Caribou from the Atlin herd were monitored with global positioning system (GPS) and very high frequency (VHF) telemetry collars (GPS 2000, LOTEK, Aurora, ON) between December 1999 and March 2003 by the Ministry of Water, Land, and Air Protection of British Columbia to address potential impacts of the proposed Tulsequah mine (Diemert 2001). Caribou were captured by helicopter net-gunning according to Wildlife Radio-Telemetry, Standards for Components of BC's Biodiversity No. 5, RIC 1998. Five GPS collars were deployed in December 1999 but drop-off mechanisms malfunctioned and collars were redeployed 10 January 2000 and scheduled to self-release in November 2000. The five GPS collars were retrieved, refurbished and re-deployed on 13 February 2001 (see timeline in Appendix A, Figure A-1). Global positioning system collars were scheduled to attempt a location every 4 hours. Seasonal locations were

collected from fixed-wing aircraft on a monthly schedule. Because GPS fix success was > 90% , we did not need to correct for habitat-induced bias in RSF models (Table 2-1. Frair et al. 2004).

RESOURCE SELECTION FUNCTION MODELING

We developed RSFs at the second- and third-order scales during winter (15 Nov – 15 May) and summer (16 May – 14 Nov). Seasons were defined based on caribou behavioral shifts and use of elevation. We employed a use-availability design described by Manly et al. (2002) by comparing resource covariates at used GPS locations to random available locations. The use-availability design results in an approximation of a true probability function because use is compared to available locations, not true absences (Keating and Cherry 2004). However, the relative probabilities are still useful for ranking habitat quality because the design approximates the logistic discriminant function (Johnson et al. 2006).

We estimated RSF's at the second-order scale by sampling availability using a 1:1 ratio of used to random available locations within the pooled seasonal home range for all GPS and VHF collared caribou, but estimated selection using only GPS data. We estimated 99% fixed kernel seasonal home ranges using Home Range Extension (Rodgers and Carr 2002) with a smoothing factor of 0.7 x the reference smoothing factor (h_{ref}) which is appropriate for large sample sizes of short-interval GPS data (Hemson et al. 2005, Robinson 2007). We used logistic regression to estimate the selection coefficients of the exponential approximation to the logistic discriminant function (Hosmer and Lemeshow 2000). To account for unbalanced sample sizes between individual caribou and temporal and spatial autocorrelation, we evaluated selection at the second-order using generalized linear mixed models (GLMM) with a random intercept for each animal ($\beta_0 + \gamma_0 j$; Hebblewhite and Merrill 2008, Bolker et al. 2009). The form of the mixed-effects model for location (i) and individual caribou (j) with a random intercept is given as:

$$w^*(x)_{ij} = \beta_0 + \gamma_{0j} + \beta_1 x_{1ij} + \ldots + \beta_n x_{nij} + \epsilon_{ij} \quad (1)$$

where $w^*(x)$ is proportional to the predicted probability of use as a function of covariates $x_{1\ldots n}$, and $\beta_{1\ldots n}$ are the selection coefficients estimated from fixed-effects logistic

regression (Manly et al. 2002). Note that because of the use-available design, the fixed and random intercepts $\beta_0 + \gamma_{0j}$ are meaningless and often dropped by convention resulting in a relative probability, although they still affect the fixed-effect coefficients (Gillies et al. 2006). Mixed-effects models were estimated with STATA 11.0 (StataCorp 2007) using xtlogit and GLLAMM (www.gllamm.org) depending on the ability of the model to converge.

At the third-order scale, we used a matched-case control logistic regression (also known as conditional logistic regression) to estimate the relative probability of caribou selection from one time step to the next. Matched-case control designs allow selection to be measured at the most biologically relevant spatial scale by sampling availability along movement paths rather than across the entire landscape (Compton et al. 2002). The limited spatial domain of the available locations allows true absences to be compared to use (Compton et al. 2002, Forester et al. 2009, Duchesne et al. 2010). We sampled availability with a 1:1 ratio of used to available locations generated from the bearing and empirical step-length and turning angle distributions of caribou movement pathways (Hosmer and Lemeshow 2000, Compton et al. 2002). Each used location was compared to a specific control point rather than the overall distribution of random points using conditional likelihood (Whittington et al. 2005). The intercept is not estimated in the conditional likelihood because inferences about β_0 are not possible without knowledge of the sampling fractions (Hosmer and Lemeshow 2000). Thus, implementation of mixed-effects conditional logistic regression is challenging (Duchesne et al. 2010). Instead of using mixed-effect models, we accounted for unbalanced sample sizes between animals using sample weighting to give equal weight to each animal. We weighted animals using the inverse of the probability that an individual caribou was included in the sample (Alldredge et al. 1998, Ferrier et al. 2002).

We included resource covariates in our analysis that influenced caribou resource selection in previous studies. All variables were screened for collinearity by calculating the Pearson's correlation between variables and using $|r| > 0.6$ as the threshold for removing a covariate (Hosmer and Lemeshow 2000). Human development covariates included distance to roads, mines, cabins and hunting camps (BC geodatabase, www.geogratis.ca) and the town of Atlin (km). Distances were generated with path

distance, which accounts for distance over terrain features, in Spatial Analyst for ArcGIS 9.3.1 (ESRI, Redlands, CA). Roads were categorized as high use (paved with chip-seal or blacktop surfaces or plowed during winter) and low use (gravel and dirt roads that were passable by 4 wheel drive vehicles excluding roads with very rough terrain and ATV trails). Mines were selected that reported work costs of > $50,000 to the Assessment Reporting Index System or were known to be active during the summer in the study area. Very few placer mines were active in the winter. Covariates of elevation (m), slope, and hillshade (30 m^2 resolution) were extracted from the TRIM digital elevation model (DEM) using Spatial Analyst for ArcGIS 9.3.1. High values of hillshade represent western slopes with high sun exposure and low values indicate shaded slopes. Vegetation community data were classified with Landsat TM satellite imagery (Chapter 4) into 13 landcover types that were important to caribou at a 30 m^2 resolution (Table 2-2). Overall classification success of the landcover model was 75%. An average index of primary productivity (greenness) was spatially modeled by averaging 16-day composites of the Normalized Difference Vegetation Index (NDVI) at a 250 m^2 resolution from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) satellites across seasons (Huete et al. 2002, Pettorelli et al. 2005). Percent snow cover was generated from 8-day composites of maximum snow extent maps at 500 m^2 resolution produced by MODIS satellites (Hall et al. 2000). We divided the number of days snow occupied a cell by the number of days in the seasonal period to generate spatial models of percent snow cover.

We used generalized additive models (GAM) to test whether coefficients were nonlinear (Hastie and Tibshirani 1990), and either transformed (e.g., square transformation) or used quadratics to capture non-linearity in GLMM models (Hosmer and Lemeshow 2000). Statistical analyses were carried out in STATA 11.0 (StataCorp 2007). To determine the importance of each variable, we used manual stepwise entry to select models and then compared a small subset of models using Akaike's information criterion (ΔAIC) to select a top model (Manly et al. 2002). Models were mapped in ArcGIS 9.3.1. at a 30 m^2 resolution. Model fit was evaluated using *k*-fold cross-validation, which measures the predictive capacity of the RSF model, an important indicator of how 'good' a habitat model is (Boyce et al. 2002a). Because RSFs describe the habitat selection of specific animals, we withheld 20% of data from each animal at

random and used the remaining 80% to estimate 5 new RSF models (Koper and Manseau 2009). Predicted values were generated for the withheld caribou observations and assigned to 10 equal habitat rank bins of available relative probabilities calculated for each cross-validated model (Boyce et al. 2002a). Spearman's rank (r_s) correlation was used to compare the RSF bins to the area-adjusted frequencies of predicted values in that bin; if an RSF model had high predictive power, then the frequency of caribou locations should increase in higher habitat ranks.

CUMULATIVE EFFECTS ASSESSMENT

To assess the cumulate effects of human development on caribou habitat, we estimated the zone of influence (ZOI) around human developments that caribou avoided (Suring et al. 1998, Dobson 2000). This was necessary because of high collinearity between human development variables (roads, mines, cabins and hunting camps and the town of Atlin, Table 2-3). The width of a ZOI buffer (the distance of avoidance) is often based on expert opinion or published literature (Anderson et al. 2002, Gallagher et al. 2004, Johnson et al. 2005, Florkiewicz et al. 2006). We estimated buffer width by breaking distance (calculated with path distance) to roads, mines, cabins, hunting camps and Atlin into distance categories. These distance categories were chosen to provide the most precise predictions of selection and categories were divided by 0.25 km to 3 km depending on the number of used locations in the buffer distance category needed to retain significance. Buffer distances were then evaluated for each development type, one by one, as categorical variables in the top RSF model. Estimates of the selectivity coefficients for each distance class and for each category of human development were recorded. Negative coefficients indicated avoidance of that distance class and neutral or positive coefficients indicated caribou use of the distance class was proportional or greater than expected based on availability. The distance class where the coefficient first changed signs from negative to neutral or positive was considered the threshold of avoidance. The threshold distance was used to generate a biologically relevant ZOI buffer around each human development type (i.e., Frair et al. 2008). We then merged the ZOI buffers for each development type to create a cumulative ZOI that was incorporated into the RSF as a binary variable which indicated when a used or available location fell within

or outside of the ZOI. This covariate represented the cumulative effect of human development and replaced the 'distance to' variables which were highly correlated.

POTENTIAL AND FUTURE HABITAT SELECTION

To model potential habitat, which we defined as the habitat available to caribou when not constrained by avoidance of human developments (Figure 2-1), we generated a RSF without the human development covariates (the ZOI) and spatially mapped the predicted probability of use in ArcGIS 9.3.1. Because caribou use was observed within a landscape that already included human developments, it is difficult to remove the effects of humans by simply modeling caribou habitat without human developments. Thus, we assumed the effects of human developments were independent of other variables (i.e., were not confounding and had low correlation) and tested this assumption by comparing the model selectivity coefficients with and without the human ZOI covariate. We classified the realized and potential habitat maps into 10 quantiles from low to high quality. High quality habitat was defined as the top 30% of habitat which included 68% of caribou locations in winter and 80% of caribou locations in summer. To quantify the change in habitat quality we subtracted the realized habitat rank from the potential habitat rank to measure how many ranks were lost in each cell when human developments were present. The difference between the habitat ranks in the potential model and the realized model was used to determine the area (km^2) in each habitat rank category (1 to 10) that was lost due to the cumulative effect of existing human developments on the landscape.

The last step of the cumulative effects assessment was to develop an approach to predict the potential effects of future development on caribou habitat quality. We used roads associated with the proposed construction of the Adanac molybdenum mine (Canadian Environmental Assessment Agency 2009) and the proposed 160 km access road to the Tulsequah multi-metal gold mine (AXYS Environmental Consulting Ltd 2004, MacLeod et al. 2008) because detailed infrastructure plans were available for the proposed mines and could be used to develop realistic scenarios. We first added the new roads to the landscape in ArcGIS 9.3.1. and generated a new ZOI that incorporated the future development scenarios. We mapped the seasonal RSFs in this new environment to evaluate the potential loss of habitat quality. We used the same methods to determine loss

of habitat ranks in each cell between realized and future habitat quality as we did between potential and realized habitat quality.

RESULTS

Eight female and 2 male caribou were radio-collared and monitored with GPS telemetry collars and 13 female and 4 male caribou were radio-collared with VHF telemetry collars. In total 16,270 GPS and 661 VHF locations were collected from December 1999 to March 2003 (Table 2-1).

CUMULATIVE EFFECTS

We first report the results of the human ZOI cumulative effects analysis so the ZOI buffers could be used in the seasonal RSF models. At the second-order, the distance category where the coefficient changed signs was similar between seasons for roads: 2 km around high use roads and 1 km for low use roads. In winter, the buffer around Atlin was 9 km compared to 3 km in summer. There was low avoidance of mines (250 m) and no avoidance of cabins and hunting camps in winter, while alternately, in summer the buffer around mines was 2 km and the buffer around cabins and hunting camps was 1.5 km (Figure 2-2). At the third-order, there was no significant avoidance of human developments during winter, and only slight avoidance during summer (250 m around roads and 4 km around Atlin).

SECOND-ORDER RESOURCE SELECTION

At the second-order scale, inclusion of a random intercept for individual caribou marginally improved model fit over the fixed-effect RSF for both seasons (Table 2-4). Caribou showed significant avoidance of both the summer and winter human ZOI buffers described above (Table 2-5). The summer and winter models cross validated in k-folds very well, confirming their high predictive capacity with an average r_s of 0.997 (SD = 0.0054), and 0.993 (SD = 0.0108) respectively.

Caribou showed strong seasonal differences in selection for resource and landcover covariates. In winter, caribou selected predominately mid-elevations (1179 m) and selected for lodgepole pine/lichen complexes, spruce/fir forests, and low elevation river valleys comprised of *Salix* spp. Caribou avoided krummholz, rock, burned lodgepole pine, alpine tundra, water and steep slopes (Table 2-5). There was a strong

correlation between landcover types and summer (growing season) average NDVI values (Appendix A, Table A-3). In winter, caribou selected intermediate NDVI values which were associated with high elevation shrublands and low elevation *Salix* dominated valleys. Caribou selected intermediate percent snow cover (60%) and high values of hillshade which represent selection for western slopes with high sun exposure.

Conversely, in the summer, caribou resource selection shifted to higher elevations (1363 m) and caribou displayed strong selection for krummholz, alpine shrubland, alpine tundra, rock, slopes with high sun exposure, and areas that had high percent snow cover in winter. In summer caribou used lodgepole pine and mixed-conifer forests less than available which also resulted in avoidance of high NDVI values. Finally, caribou were negatively associated with water and steep slopes.

THIRD-ORDER RESOURCE SELECTION

At the third-order scale, the winter conditional logistic regression model had relatively low predictive performance with an average r_s of 0.704 (SD = 0.1295). The most parsimonious winter third-order model did not include a human ZOI buffer. Since inferences of resource selection at the third-order represent where caribou chose to move at the next time step, we mapped selection within a 2 km buffer (95th percentile of movement distance) around used locations. Caribou occurrence was positively related to lodgepole pine/lichen forests, spruce/fir forests, mixedwood stands, and low slopes. Caribou demonstrated avoidance of alpine tundra and areas with high percent winter snow cover. Within the limited extent of the third-order scale, caribou were positively associated with high elevation. This resulted in selection for elevations between 1000 and 1500 m (Table 2-6).

In summer, the third-order model had higher predictive capacity with an average r_s of 0.920 (SD = 0.0279). Caribou avoided the summer third-order human ZOI buffer. Selection was mapped within a 2.7 km buffer (95th percentile of movement distance) around used locations. Within this extent, caribou exhibited selection for alpine tundra, and high elevations. The probability of occurrence also increased in mixedwood forests, areas of high percent snow cover during the previous winter, high NDVI values and low slopes with high sun exposure. Caribou generally avoided water, mixed conifer forests, and areas with high percent snow cover during the summer (Table 2-6).

POTENTIAL AND FUTURE RESOURCE SELECTION

At the second-order, seasonal RSF models were used to map habitat selection of the Atlin herd in the study area that included all known VHF and GPS caribou locations. Coefficients between the realized and potential GLMM models were very similar (Appendix A, Table A1, A2), confirming the validity of our assumption that removing human activity would approximate potential habitat. Roughly 30% of the study area was considered high (RSF ranks 8-10), 30% medium (RSF ranks 5-7) and 40% low (RSF ranks 1-4). In winter, the potential habitat map (modeled without human ZOI coefficient) had 276.2 km^2 more predicted high quality habitat than the realized habitat map (Figure 2-4). Thus, existing human developments were responsible for a 7.9% decrease in high quality habitat available within the study area, mostly in the vicinity of the town of Atlin (Figure 2-5 and 2-6). In terms of future impacts, the development of an access road to the Tulsequah mine led to the loss of 31.1 km^2 of high quality winter habitat, while new roads around the Adanac mine site generated a minimal loss of 0.3 km^2 of high quality habitat. Together the two mines decreased the amount of high quality habitat by 1% in winter.

The overall effect of human development was weaker in summer. At the second-order, 60.8 km^2 of high quality habitat was avoided due to existing human development, which totaled 1.75% of the high quality habitat available (Figure 2-4). The addition of the Tulsequah access road and the Adanac mine roads decrease the amount of high quality habitat by 7.78 km^2 or 0.22% (Figure 2-7 and 2-8). At the third-order, during summer, caribou avoidance of the ZOI buffer resulted in the loss of 6.4 km^2 of high quality and 21.9 km^2 of medium quality habitat (Figure 2-9) within the 3,828 km^2 that was mapped along the movement paths of caribou. This resulted in the loss of 0.55% of high and 1.9% of medium quality habitat (Figure 2-10 and 2-11). The addition of the Tulsequah road did not affect high quality habitat, but decreased medium quality habitat by 8.3 km^2, a 0.73%. Finally, during winter at the third-order, there was no significant avoidance of human developments, thus the realized and potential maps are equivalent (Figure 2-12).

DISCUSSION

This study clearly demonstrated that northern mountain woodland caribou avoid multiple types of human development, and the indirect effect of avoidance has important cumulative impacts on the potential habitat available to the Atlin caribou herd. We found that caribou avoidance of human developments varied between scales, seasons, and development types. Avoidance is defined as a reduction in use compared to what would be expected based on availability. In the context of resource selection, avoidance does not indicate that caribou never occurred near developments, but rather, areas near developments were used less than expected. We also found that selection decisions were made by caribou in a hierarchical fashion with increased sensitivity to human developments at the larger scale. This is consistent with other studies that have demonstrated that northern mountain caribou avoid predation risk at large scales (Rettie and Messier 2000, Johnson et al. 2001, Gustine et al. 2006). It also correlates with the emerging consensus in the caribou literature that the direct and indirect effects of human development are the strongest at the landscape scale (Environment Canada 2008, Serrouya et al. 2008, Sorensen et al. 2008). The significant avoidance of human developments at the second-order restricts avoidance at the third-order because caribou likely maintain individual home ranges only in areas far from human developments. Since human developments are often correlated in space they can have confounding effects when modeled together. We used a biologically relevant cumulative ZOI to incorporate multifarious human developments into the two-scale seasonal RSF models. The ZOI reduced model complexity and served as a simple tool to evaluate a large range of human development types as one unit.

Avoidance of human development types varied between seasons. In winter, we found caribou avoided high use (plowed) roads by 2 km. High use roads in the study area converge on the town of Atlin and connect local residences, an airstrip, placer mines, forestry activities, and recreational areas. Within 10 km of Atlin, the road density is much higher (0.53 $km \cdot km^{-2}$) than the average across the study area (0.11 $km \cdot km^{-2}$). The probability of caribou use was much lower than expected within 9 km of Atlin during winter. This level of avoidance has also been demonstrated in studies of reindeer (*Rangifer tarandus tarandus*) in Norway. At large spatial scales, Nellemann et al. (2001, 2003) found that wild reindeer avoid areas within 5 km of development and reindeer

densities near infrastructure declined by up to 92% in winter. In Canada, Dyer et al. (2001) studied the distribution of woodland caribou in association with human infrastructure in the Athabasca oil sands of northern Alberta. Their results established that caribou avoided areas 250 m from roads and seismic lines and 1,000 m from oil well sites and that avoidance was greatest during winter. Woodland caribou have also been shown to avoid mining activity by 4 km in winter (Weir et al. 2007).

Strong avoidance of human developments during winter is important because winter is often the season when human activity on the landscape is the lowest. Studies on reindeer and caribou have suggested that avoidance behavior may occur due to infrastructure alone (Nellemann and Cameron 1998, Vistnes and Nellemann 2001). However, in our study area, caribou selected for low elevation forests which are also often sites for roads, towns and cabins. Furthermore, snowmobile activity has been increasing in the Canadian north, is known to have major impacts on winter caribou and reindeer habitat use and behavior (Reimers et al. 2003, Seip et al. 2007), and could be a contributing cumulative impact in our study area. Conversely, in summer, caribou selected for high elevation habitat where conflict with human developments is less severe. However, while we found that caribou avoided roads similarly across seasons, avoidance of mines, cabins and hunting camps was only observed during summer. The avoidance of mines by 2 km and cabins and hunting camps by 1.5 km during the summer corresponds to the increased level of human activity on the landscape due to active placer mines and the ease of access to the road and ATV networks.

The results of our RSF models confirm many habitat relationships found in previous studies. In winter, at the second-order scale, we found that caribou in the Atlin herd selected lodgepole pine/lichen complexes, spruce/fir and mid-elevations; all of which are typical of northern mountain populations (Poole et al. 2000, Florkiewicz et al. 2006, Gustine and Parker 2008). During summer at both scales, woodland caribou selected alpine habitats, which is likely a result of selection for new high quality forage and relief from insect harassment (Ion and Kershaw 1989). Forage quality (nitrogen content) has been correlated with snowmelt gradients in Sweden at multiple spatial scales (Mårell et al. 2006). This may explain summer selection for areas that had high percent

snow cover during the previous winter and suggests that selection for forage quality is important during summer at both spatial scales.

However, our third-order winter model had low predictive performance. This could be because the predictive capacity of RSF models declines at finer spatial scales (Boyce 2006, Hebblewhite et al. 2008). Additionally, the factors that drive selection at the third-order may differ from the environmental variables we measured. Studies have shown that at fine spatial scales caribou make movement decisions based on snow conditions and the amount and specific species of lichen available for forage (Johnson et al. 2001, 2002b). Our study did not specifically measure species composition of lichen and MODIS snow cover data does not reflect snow depth or condition at a fine scale. If these small scale variables were driving selection at the third-order, our models would be expected to perform poorly in the absence of fine scale data.

We used an innovative approach to evaluate the cumulative impacts of human development on caribou by comparing estimates of potential and realized habitat. This allowed us to determine that 8% of high quality winter habitat and 2% of high quality summer habitat was lost due to indirect avoidance of existing human developments at the second-order scale. Our results also show that this occurred through avoidance of areas at the second-order home range scale, not through fine-scale avoidance behavior; thus, these impacts resulted in a reduction in the realized herd range. Our approach was conservative, in that the ZOI buffer limited the amount of habitat that could be affected by human development to the area within the buffer. Johnson et al. (2005) studied caribou habitat selection in the Canadian high arctic, another northern system impacted by increasing human development. They examined the amount of habitat lost due to avoidance of human development with ZOI buffers based on published literature as well as coefficients of 'distance to' human developments. They found that the ZOI showed less extreme results of avoidance than models that included distance covariates. Their ZOI predicted that 6% of high quality habitat was avoided during the post calving season, but when disturbance coefficients were modeled with quadratic functions of distance to development, the amount of high quality habitat lost increased to 37%. This suggests that the effects of human development were far reaching (up to 33 km from major developments in the Johnson et al. (2005) study, and similarly, quadratic functions

indicated avoidance up to 30 km from Atlin in our study area). However, at the second-order scale, quadratic functions may reflect landscape-level patterns in the availability of human development, and not avoidance per se. Therefore, we contend that when based on empirical avoidance behavior of caribou, ZOI buffers are an important tool because they are easily replicated, conservative, and allow the cumulative impacts of several human developments to be analyzed simultaneously.

Understanding how future or proposed developments will affect habitat quality is an important consideration for land managers. We predicted that the proposed development of two new mines in the study area would decrease high quality caribou habitat by 31.4 km^2, or 1% of the entire herd range in winter, and 7.8 km^2 or 0.22% in summer. This potential indirect habitat loss, when combined with current avoidance of existing developments, could have consequences for a population that may be in decline (Taku River Tlingit First Nation and British Columbia 2010) because slight reductions in high quality habitat have the potential to hasten further declines. Moreover, our estimates of the effects of indirect habitat loss are likely conservative for a number of reasons. The proposed Tulsequah road extends 88 km within the study area. Of this distance, approximately 35 km is adjacent to current roads that are already accounted for with a ZOI in the realized RSF. Therefore, the impact of the proposed road on the future development scenario is limited to areas where the proposed road intersected undeveloped habitat. Furthermore, as activity levels change in the future, it is important to recognize that the ZOI is subject to spatio-temporal changes in human land use. The amount of activity on a large mining road would likely be greater than what is currently observed on current high use roads in the study area. Likewise, development of the Adanac mine is planned to include housing for approximately 250 workers, which is comparable to the size of the current town of Atlin. Because of this, the 2 km buffer around the proposed Tulsequah road and the Adanac road developments are likely conservative estimates of the potential ZOI. For example, by increasing the ZOI buffer around the Adanac development from 2 km to 5 km, 8.3 km^2 more high quality summer habitat is lost (0.3% of high quality habitat in the study area).

Additionally, our study only predicts the changes in resource selection by caribou due to avoidance of human developments during summer and winter, and does not

address other important consequences of development. Before proposed development occurs, additional potential impacts should be considered including: barriers to movement, habitat fragmentation, increased access, and direct and indirect habitat loss during calving and rutting periods when caribou may have heightened sensitivity to disturbance. Environmental assessments for both proposed mines have identified significant effects of the mine sites and access roads on important caribou seasonal ranges such as low elevation winter and spring habitat as well as fragmentation of important calving areas (AXYS Environmental Consulting Ltd 2004, Berger 2006). Other impacts include localized habitat alienation, project-related moralities, and habitat loss as a result of blasting (Berger 2006).

Variability associated with the satellite image landcover model may have affected our ability to predict the distribution and quality of caribou habitats. In validation tests, the landcover classification had an overall classification success of 75%, which is considered good for a 14 class landcover model (McDermid et al. 2009b). Of particular importance, the classification success of LP/lichen, was 56% and 61% (user's and producer's accuracy respectively), reducing our ability to identify high value winter habitats. This was likely because of the difficulty in separating lodgepole pine from other coniferous landcover types (Chapter 4). In the southern portion of the study area, we identified inconsistencies between the landcover classification and provincial forest cover data, with the classification identifying less LP/lichen habitat than the forest cover data. As a result, there could be more high quality winter habitat along the proposed Tulsequah road corridor than our model predicts. In fact, a winter caribou habitat suitability model, jointly developed by BC and the TRTFN, based on provincial forest cover data (McKay et al. 2008), predicted more high quality habitat in the proposed road corridor than the RSF models. These spatial discrepancies may have limited the extent of predicted high quality habitat loss associated with the proposed development of the Tulsequah road in our analysis.

While other studies have demonstrated that human development can result in the loss of available habitat (Dyer et al. 2001, Mahoney and Schaefer 2002, Nellemann et al. 2003), few have demonstrated the indirect avoidance of high quality habitat (but see: Johnson et al. 2005). We suggest that the avoidance of high quality habitat may have

demographic consequences, though we were not able to test this hypothesis directly in this study. Displacement, through indirect avoidance of foraging areas, could lead to use of less suitable habitats and cause crowding and overgrazing (Nellemann et al. 2003). Decreased forage availability and lower nutrient intake have been shown to reduce reproductive rates (Nellemann and Cameron 1996, Cameron et al. 2005). Indirect habitat loss may also influence individuals' ability to circumvent harsh snow conditions and local habitat variables. Reduction in the amount of preferred habitat has the potential to alter predation risk by making caribou locations more predictable and thus more vulnerable to hunting by animal predators and humans (Stuart-Smith et al. 1997, James and Stuart-Smith 2000, Dyer et al. 2001).

Our approach relied on the assumptions that we could statistically remove human impacts on the landscape to approximate potential habitat and that the probability of occurrence is related to quality. We found that removing the human ZOI from models did not significantly affect other covariates in the model, thus we established that human developments were independent of other variables. This may not be the case in other areas where extensive habitat loss could potentially mask true habitat preferences of sampled animals. In these situations, occurrence may not always be predictive of habitat quality (van Horne 1983). Individuals select risky habitats which decrease survival (Nielsen et al. 2006). These habitats are often called attractive sinks (Pulliam 1988) or ecological traps (Gates and Gysel 1978) where individuals experience high mortality, but populations are maintained by immigration from source areas in better quality habitats. Attractive sinks are common in human-altered habitats because species are unable to adapt to mortality risks that were absent in their evolutionary history (Delibes et al. 2001, Donovan and Thompson 2001, Schlaepfer et al. 2002). If this is the case, modeling the loss of high quality habitat may underestimate negative demographic consequences. Though our approach to estimating habitat loss is not without its caveats, it has the potential to aid conservation efforts by identifying the underlying habitat quality in areas that are avoided. For example, the winter map of potential habitat revealed that the areas surrounding the town of Atlin and high use roads contain high quality habitat that is used less than expected under current human development (Figure 2-5). Avoidance of human development at the second-order scale implies a demographic response if caribou

mortality increases near human activity, as suggested by recent studies on caribou (McLoughlin et al. 2003, Wittmer et al. 2007).

While the cumulative impact of human developments in our study area may seem minor compared to the severe threats facing more southern caribou herds, these impacts will likely be exacerbated by climate changes predicted to be pronounced in northern ecosystems (Hinzman et al. 2005). Changes in date of snowmelt, plant and insect phenology, species distributions, extreme weather events, and ecosystem alterations due to tree-line advance and loss of alpine environments may challenge the ability of caribou and reindeer to adapt to changing environments (Wilmking et al. 2004, Vors and Boyce 2009, Kuhn et al. 2010). Post et al. (2008) has found that warming increased the variability of plant phenology in Greenland and impaired the ability of caribou to forage selectively resulting in effects on productivity. These and other unforeseen consequences of climate change emphasize the need to minimize levels of human disturbance within high quality caribou habitat (Vors et al. 2007).

The importance of *Rangifer* to northern indigenous cultures in Canada, Alaska, Greenland, Scandinavia, and Siberia, combined with a growing industrial economy and the predicted effects of climate change on these northern ecosystems, requires proactive and collaborative management to ensure the persistence of caribou into the future. While we have limited long-term scientific data of the dynamics of northern landscapes and the species within them, there is a wealth of traditional ecological knowledge within northern indigenous communities. Incorporation of traditional ecological knowledge with cumulative effects studies has the potential to increase our understanding of caribou-habitat dynamics and provide alternate descriptions of potential habitat (Freeman 1992, Menzies and Butler 2006).

Table 2-1. Summary of 27 caribou collared with Global Positioning System (GPS) and Very High Frequency (VHF) collars. Table includes dates collared, sex, number of locations, and fix rates from individual (caribou ID) northern mountain woodland caribou within the Atlin herd in northern British Columbia, from December 1999 to March 2003. Data collected and provided by the Ministry of Water, Land, and Air Protection of British Columbia.

Caribou ID	Start Date	End Date	Collar Type	Sex	# VHF locations	# GPS locations	Fix Rate
C1	1/10/2000	11/14/2000	GPS	F	16	1719	92.67%
C2	1/10/2000	11/13/2000	GPS	F	16	1793	96.87%
C3	1/10/2000	10/20/2000	GPS	F	12	1640	96.07%
C4	1/10/2000	11/10/2000	GPS	F	14	1773	96.78%
C5	1/10/2000	3/7/2000	GPS	F	6	339	98.85%
C22	2/13/2001	11/30/2001	GPS	M	16	1709	98.44%
C23	2/13/2001	11/29/2001	GPS	F	13	1669	96.25%
C24	2/13/2001	12/18/2001	GPS	F	12	1784	96.59%
C25	2/13/2001	12/17/2001	GPS	M	13	1803	97.88%
C26	2/13/2001	1/27/2002	GPS	F	14	2041	97.89%
C6	12/6/1999	3/19/2003	VHF	F	38		
C7	12/11/1999	3/19/2003	VHF	F	39		
C8	12/8/1999	3/27/2003	VHF	F	38		
C9	12/6/1999	3/19/2003	VHF	F	41		
C10	12/6/1999	3/19/2003	VHF	F	38		
C11	12/6/1999	12/29/2000	VHF	M	16		
C12	12/6/1999	3/19/2003	VHF	F	35		
C13	12/3/1999	3/19/2003	VHF	F	39		
C14	12/11/1999	3/19/2003	VHF	M	39		
C15	12/11/1999	3/27/2003	VHF	F	40		
C16	12/3/1999	10/13/2001	VHF	F	24		
C17	12/11/1999	2/26/2003	VHF	M	32		
C18	12/11/1999	4/7/2001	VHF	F	6		
C19	12/6/1999	10/11/2001	VHF	F	26		
C20	12/3/1999	3/4/2003	VHF	F	41		
C21	3/21/2001	3/19/2003	VHF	F	20		
C27	3/21/2001	3/19/2003	VHF	M	17		
Total: 27					**661**	**16270**	

Table 2-2. Landcover types classified with Landsat TM satellite imagery (Chapter 4) in the home range of the Atlin herd of northern mountain woodland caribou in northern British Columbia. Overall classification success of the landcover classification model was 75%.

Cover Type	Description
LP/Lichen	Level areas with well-drained soils that support stands of lodgepole pine (*Pinus contorta var. latifolia*) and an understory of *Cladina* and *Cladonia* species.
Spruce/Fir	Forest dominated by white spruce (*Picea glauca*) and sub-alpine fir (*Abies lasiocarpa*) with minor components of lodgepole pine.
Mixed Conifer	Older stands that comprise variable composition of white spruce, sub-alpine fir, and lodgepole pine.
Aspen	Over-grown, high shrub, or closed stands of trembling aspen (*Populus tremuloides*) that may contain black cottonwood (*Populus balsamifera spp. trichocarpa*).
Mixedwood	Medium-aged stands that comprise variable composition of white spruce, sub-alpine fir, lodgepole pine, trembling aspen and black cottonwood.
Krummholz	Windswept landscape near tree-line characterized by stunted vegetation in a variety of species including, white spruce and sub-alpine fir.
Alpine Tundra	Rolling alpine tundra characterized by sedge and altai fescue (*Festuca altaica*) dominated meadows. Mountain heather (*Cassiope spp.*), crowberry (*Empetrum nigrum*), mountain avens (*Dryas spp.*) and lichen communities are also common.
Low Valley Salix	Shrub, sedge, and forb dominated lowlands with high water table usually dominated by *Salix* species.
Alpine Shrub	Alpine environments dominated by low-height plant species such as scrub birch (*Betula glandulosa*) and *Salix* species
Rock/Talus	Rocky terrain with very sparse vegetation. Can include lichen cover of *Umbilicaria, Cetraria* and *Cladina* species.
Snow/Ice	High elevation areas above the tree-line or otherwise dominated by glaciers and heavy snow.
Water	Area of low slope and depression where water aggregates and the water table is above grade.
Burned LP	Recent burns (since 1950) comprising dense stands of young lodgepole pine.

Notes: Abbreviations are LP, lodgepole pine (*Pinus contorta var. latifolia*).

Table 2-3. Pearson's correlation *r* between distance to low and high use roads, the town of Atlin, cabins and hunting camps and placer and hardrock mines in the home range of the Atlin herd of northern mountain woodland caribou in northern British Columbia. Summer variables shown shaded in the bottom left and winter variables shown in top right.

Distance to (km):	Low use roads	High use roads	Atlin	Cabins and hunting camps	Mines
Low use roads	1	0.811	0.656	0.320	0.484
High use roads	0.872	1	0.527	-0.009	0.138
Atlin	0.865	0.937	1	0.750	0.794
Cabins and camps	0.714	0.419	0.459	1	0.870
Mines	0.728	0.435	0.494	0.861	1

Table 2-4. Results of model selection for caribou second-order resource selection models of the Atlin herd of northern mountain woodland caribou in northern British Columbia. Selection was measured in winter (Nov15-May15) and summer (May16-Nov14) from 2000-2002.

winter	N	LL	K	ΔAIC
Random intercept	13862	-7759.2	19	0
Fixed-effect	13862	-7766.3	19	14.4

summer	N	LL	K	ΔAIC
Random intercept	18678	-9409.1	17	0
Fixed-effect	18678	-9408.5	17	20.4

Notes: Abbreviations are LL, log likelihood; k, the number of parameters; ΔAIC, difference from the model with the lowest Akaike information criterion value; and N, number of observations

Table 2-5. Estimates of caribou selectivity (β) coefficients and standard errors (SE) from generalized linear mixed models with a random intercept at the second-order scale for the Atlin herd of northern mountain woodland caribou in northern British Columbia. Selection was measured in winter (Nov15-May15) and summer (May16-Nov14) from 2000-2002. Positive selectivity coefficients indicate selection for that covariate and negative selectivity coefficients indicate avoidance. Squared terms (such as slope^2) indicate that the relationship was quadratic (i.e., caribou selected for intermediate slopes). Selection for high values of hillshade represent selection for western slopes with high sun exposure. In the winter model, percent snow cover coefficients were square transformed.

Second-order	Summer		Winter	
Covariate	**Selectivity β**	**SE**	**Selectivity β**	**SE**
LP/lichen	-0.733	0.1465	0.569	0.0624
Mixed Con	-0.857	0.0920		
Krummholz	0.329	0.1131	-0.919	0.1399
Burn LP			-0.866	0.1684
Spruce/fir			0.232	0.0625
Low Valley Salix			0.687	0.0937
Alpine Shrub	0.495	0.1031		
Alpine Tundra	0.596	0.1117	-0.699	0.1634
Rock	0.298	0.1388	-1.659	0.6140
Water	-3.198	0.3123	-0.827	0.1519
Elevation	0.012	0.0012	0.017	0.0012
Elevation^2	-4.44E-06	4.540E-07	-7.23E-06	5.640E-07
Slope	0.037	0.0078	-0.050	0.0034
Slope^2	-0.002	0.0002		
Hillshade	0.004	0.0006	0.006	0.0009
NDVI summer	-2.71E-04	1.660E-05	0.003	0.0003
NDVI summer^2			-2.83E-07	2.310E-08
Percent Snow winter	8.212	0.3753	9.552	0.6575
Percent Snow winter^2			-7.655	0.4531
Human ZOI summer	-0.478	0.0608		
Human ZOI winter			-0.954	0.0739
Constant	-14.990	0.6986	-22.795	1.1244

Notes: Abbreviations are LP, lodgepole pine; NDVI, Normalized Difference Vegetation Index; ZOI, cumulative human Zone of Influence.

Table 2-6. Estimates of caribou selectivity (β) coefficients and standard errors (SE) from conditional logistic regression at the third-order scale for the Atlin herd of northern mountain woodland caribou in northern British Columbia. Selection was measured winter (Nov15-May15) and summer (May16-Nov14) from 2000-2002. Positive selectivity coefficients indicate selection for that covariate and negative selectivity coefficients indicate avoidance. Selection for high values of hillshade represent selection for western slopes with high sun exposure. Avoidance of the human zone of influence was not significant in winter and thus not included in the model.

Third-order	Summer		Winter	
Covariate	**Selectivity β**	**SE**	**Selectivity β**	**SE**
Mixed Conifer	-0.466	0.0747		
Mixed Wood	0.873	0.2666	0.331	0.0860
Alpine Tundra	0.129	0.0564	-0.606	0.2818
LP/Lichen			0.311	0.0716
Spruce/Fir			0.264	0.0708
Water	-3.654	0.4643		
Elevation	0.006	0.0003	0.002	0.0005
Slope	-0.038	0.0032	-0.017	0.0050
Hillshade	0.004	0.0007	0.009	0.0012
NDVI summer	6.93E-05	2.040E-05		
Percent Snow winter	4.271	0.6386	-1.308	0.3714
Percent Snow summer	-4.147	0.2913		
Human ZOI summer	-1.182	0.3375		

Notes: Abbreviations are LP, lodgepole pine; NDVI, Normalized Difference Vegetation Index; ZOI, cumulative human Zone of Influence.

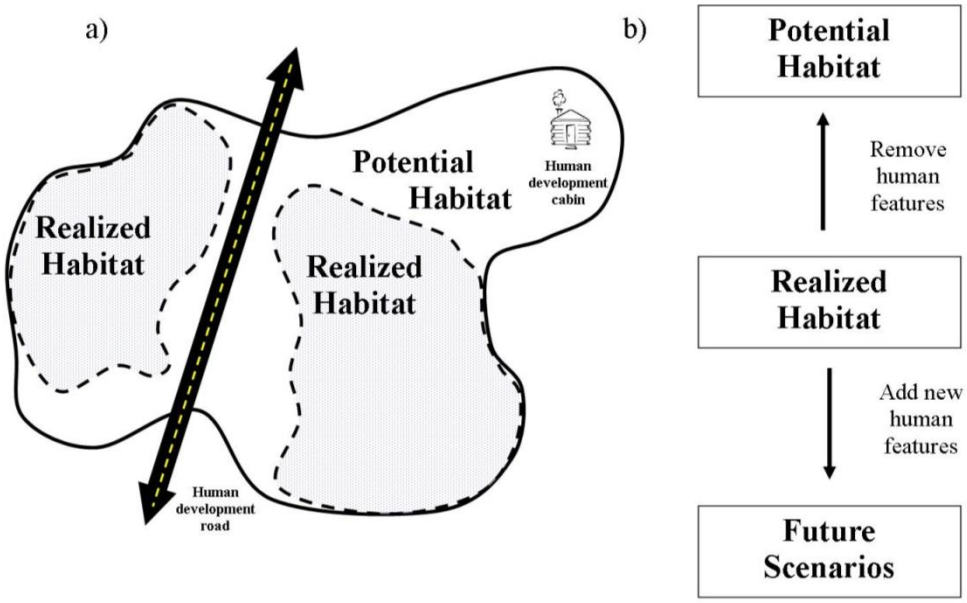


Figure 2-1. Theoretical spatial relationship between potential and realized habitat (a) and the conceptual relationship between potential habitat, realized habitat (modeled with resource selection functions), and future development scenarios (b).

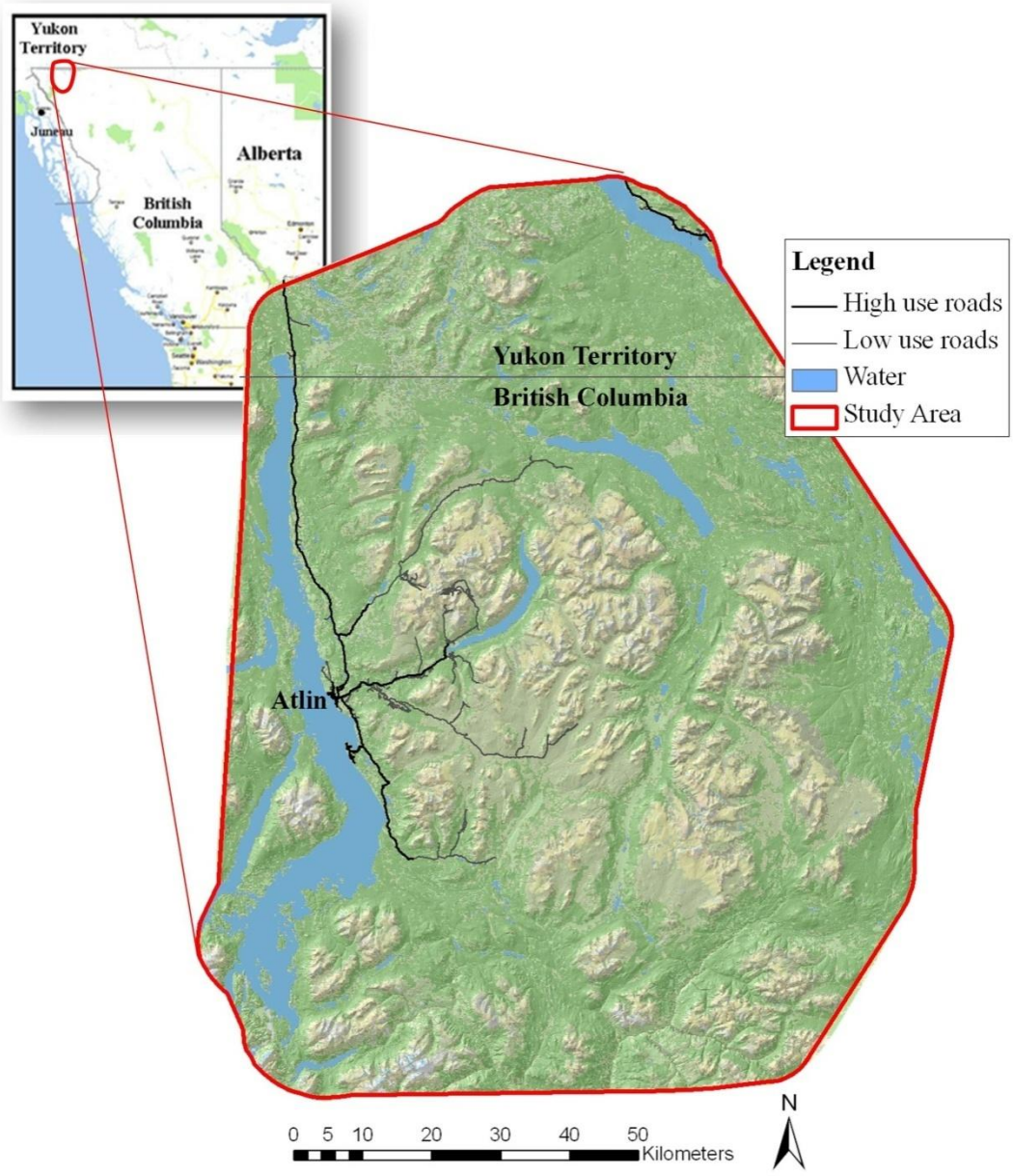


Figure 2-2. General location of the 11,594 km^2 study area (buffered minimum convex polygon of all known Global Positioning System (GPS) and Very High Frequency (VHF) caribou locations) in North America on the boarder of the Yukon Territory and British Columbia, Canada.

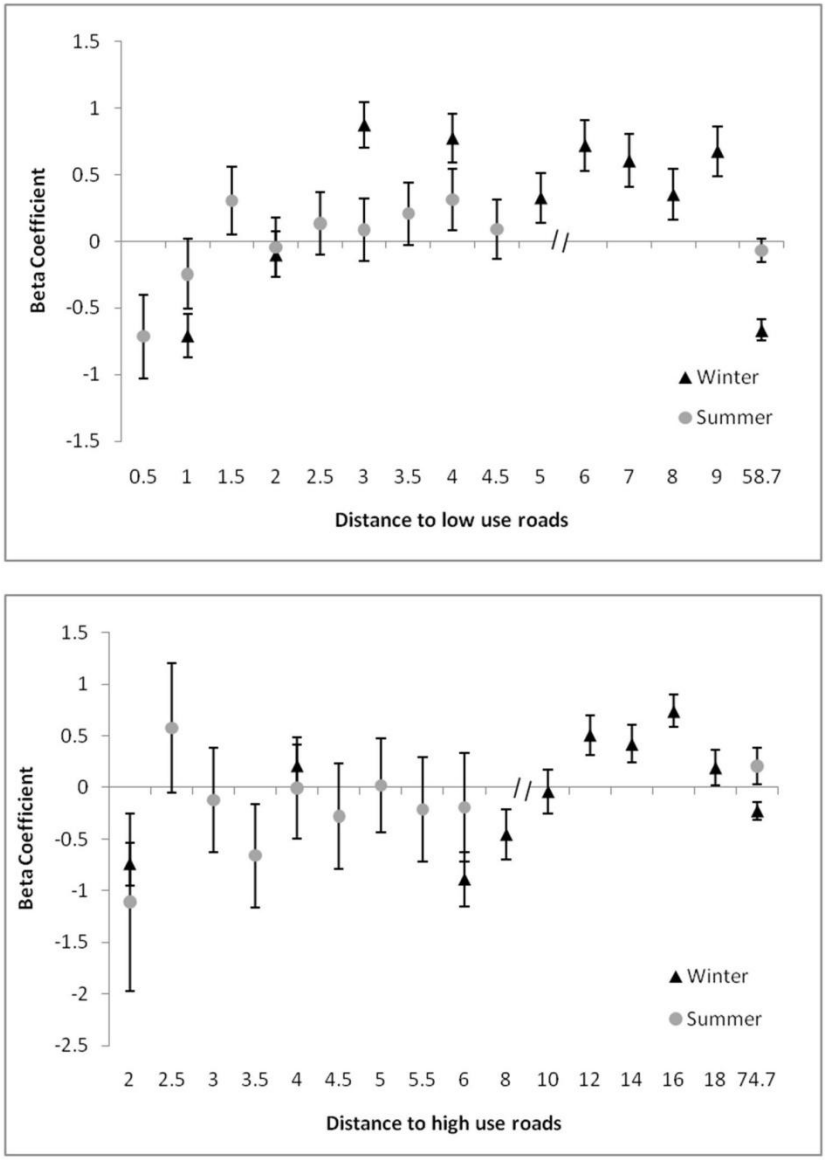
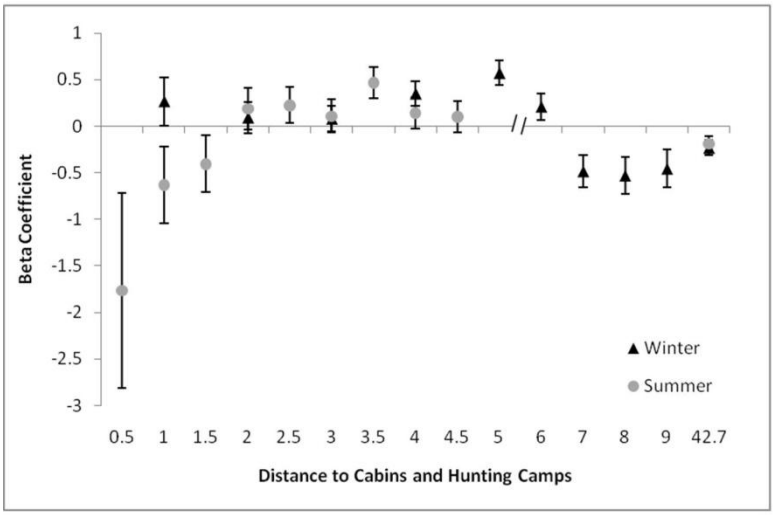
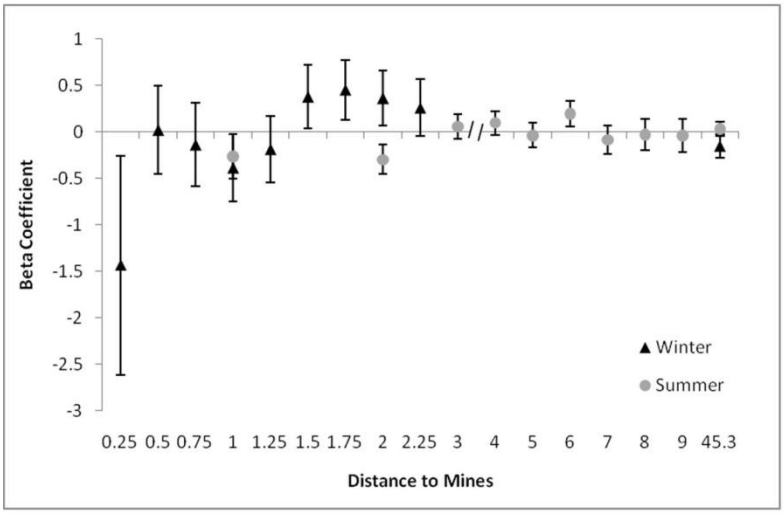


Figure 2-3. Selectivity (beta) coefficients for distance (km) to high and low use roads, cabins and hunting camps, mines, and Atlin divided into distance categories for the Atlin northern mountain woodland mountain caribou in northern British Columbia, from 2000-2002. Negative beta coefficients indicate avoidance, positive coefficients indicate selection. The distance category where the coefficient and associated confidence intervals changed signs was the distance that was used to generate the binary variable of the cumulative zone of influence. The buffers were 2 km around high use roads and 1 km around low use roads in summer and winter, no buffer around cabins and hunting camps in winter and 1.5 km for summer, 0.25 km around mines in winter and 2 km in summer and finally 9 km around Atlin in winter and 3 km in summer. Figure continued on following page.





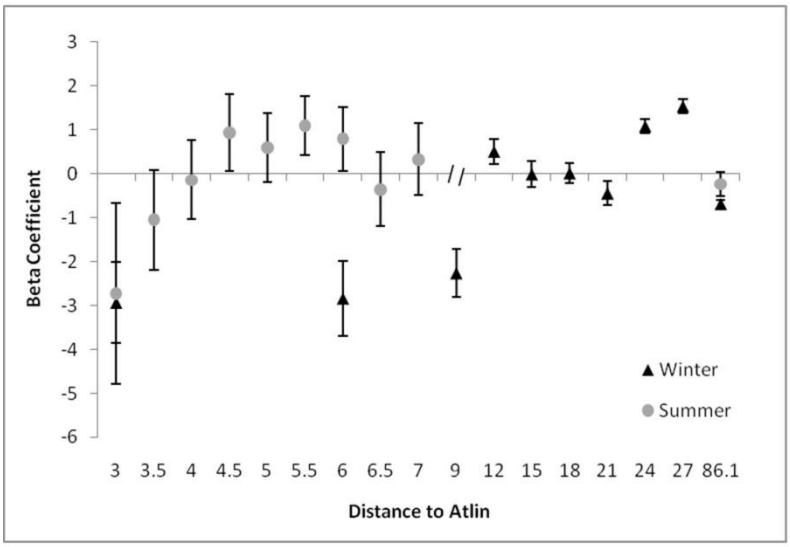
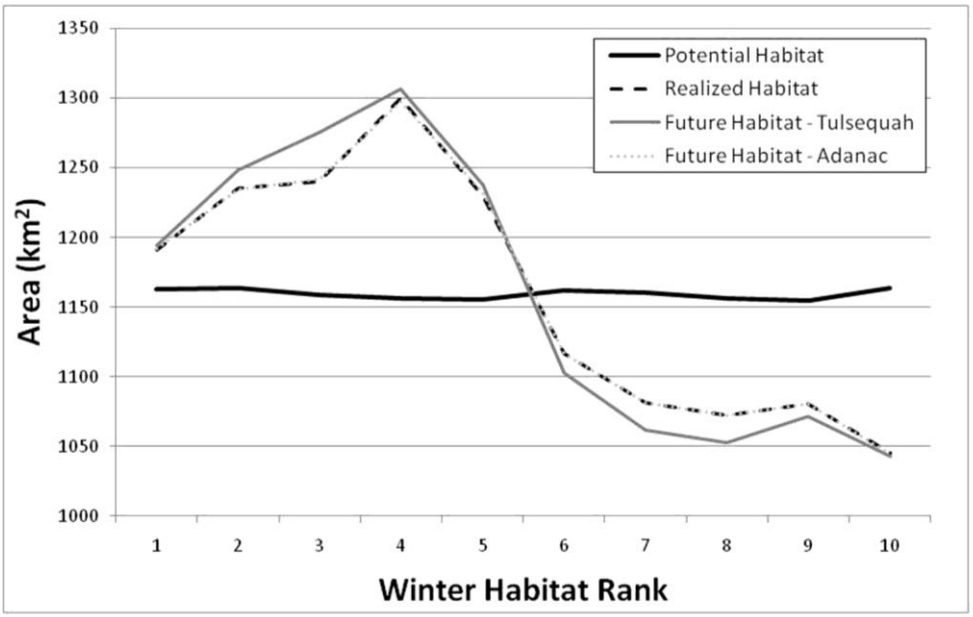


Figure 2-3. Continued.



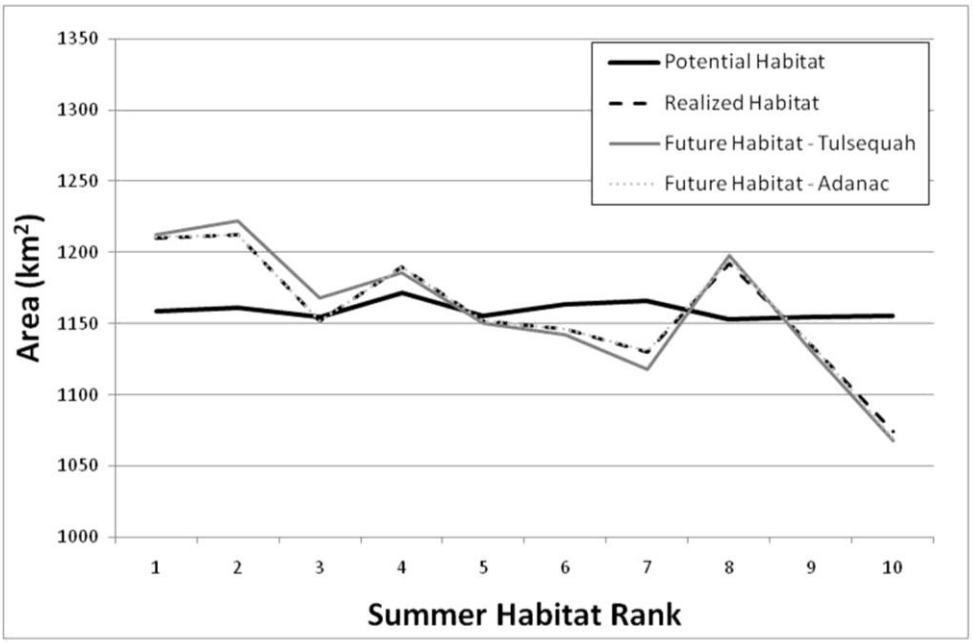


Figure 2-4. Habitat loss associated with the avoidance of human developments at the second-order scale for winter and summer for the Atlin northern mountain woodland caribou herd in northern British Columbia, from 2000-2002. The difference between potential and realized habitat ranks 8-10 can be considered the amount of high quality habitat that was lost due to current human development (276.2 km^2 in winter and 60.9 km^2 in summer). The difference between realized and future habitat ranks 8-10 can be considered the amount of high quality habitat that is lost due to the development of two new mines (31.4 km^2 in winter and 7.8 km^2 in summer). Total study area size was 11,593.8 km^2.

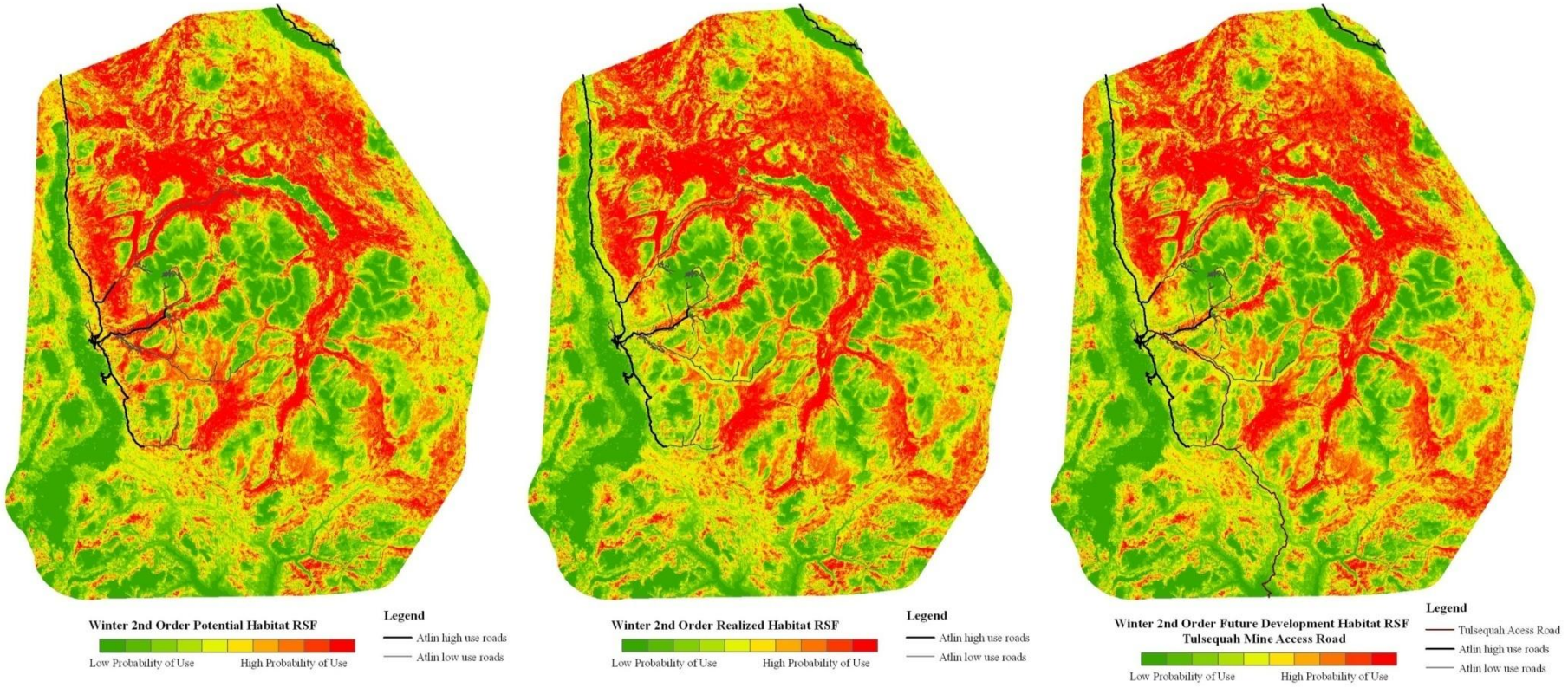


Figure 2-5. Second-order winter resource selection function maps of the potential (left) realized (middle) and future development (right) habitat of the Atlin herd of woodland caribou in northern British Columbia, Canada. The relative probability of selection is scaled between low (green) and high (red). The future development scenario that is mapped is the addition of the Tulsequah mine access road.

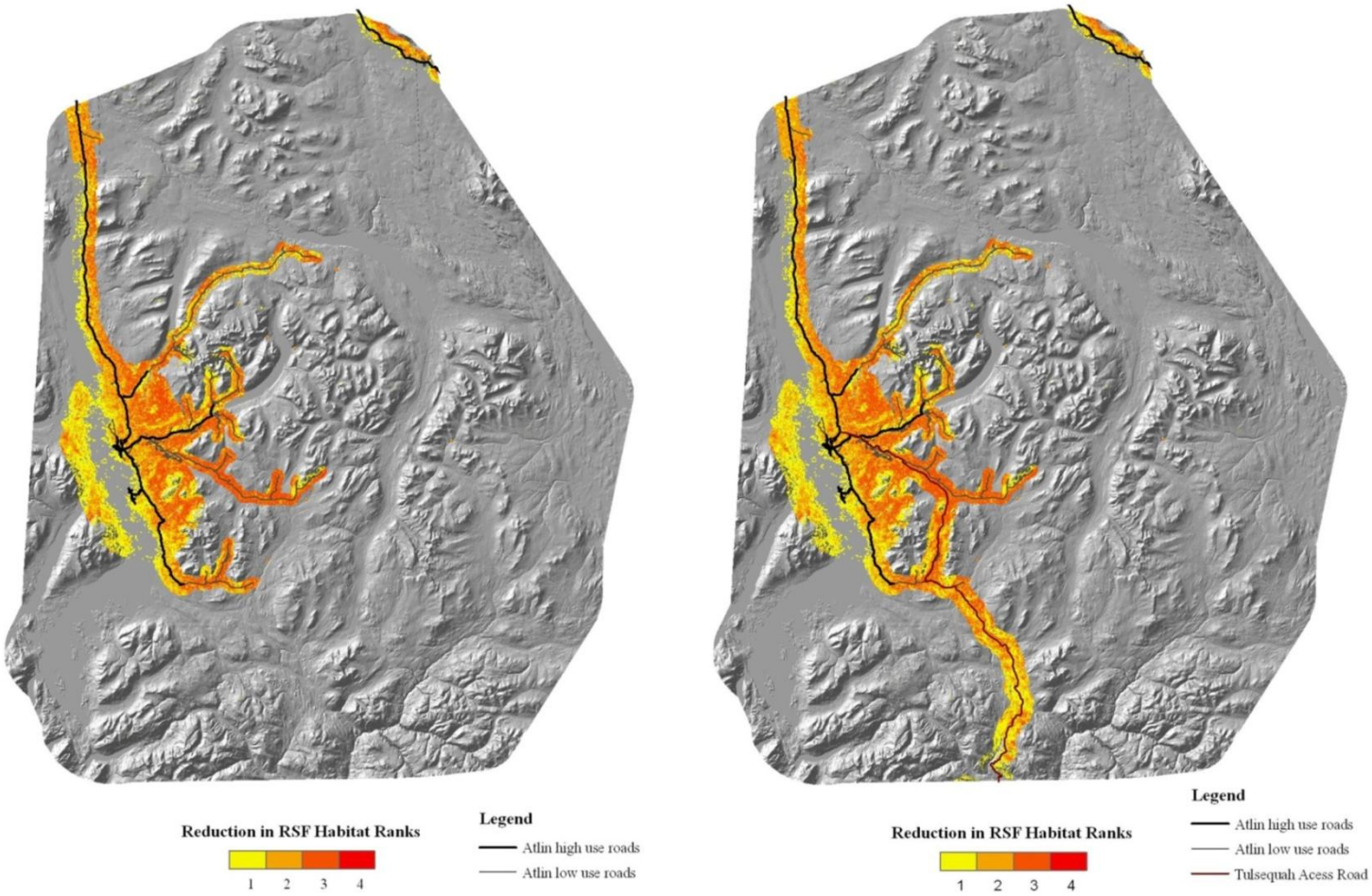


Figure 2-6. The reduction in habitat ranks between winter second-order potential and realized habitat (left) and potential and future habitat (right). Red indicates the loss of 4 habitat ranks in that cell. The reduction in rank was used to determine the area (km^2) in each habitat rank category that was lost due to the cumulative effect of existing and future human developments on the landscape.

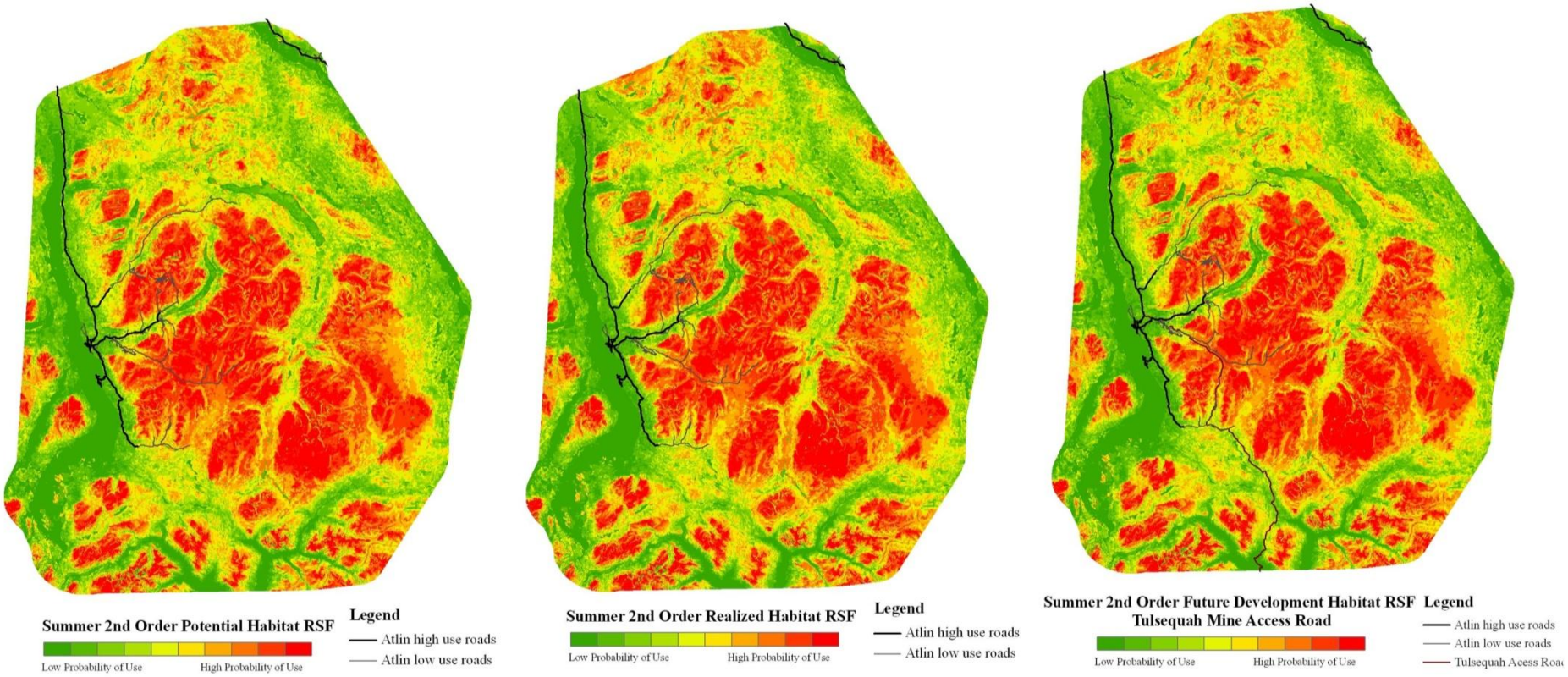


Figure 2-7. Second-order summer resource selection function maps of the potential (left) realized (middle) and future development (right) habitat of the Atlin herd of woodland caribou in northern British Columbia, Canada. The relative probability of selection is scaled between low (green) and high (red). The future development scenario that is mapped is the addition of the Tulsequah mine access road.

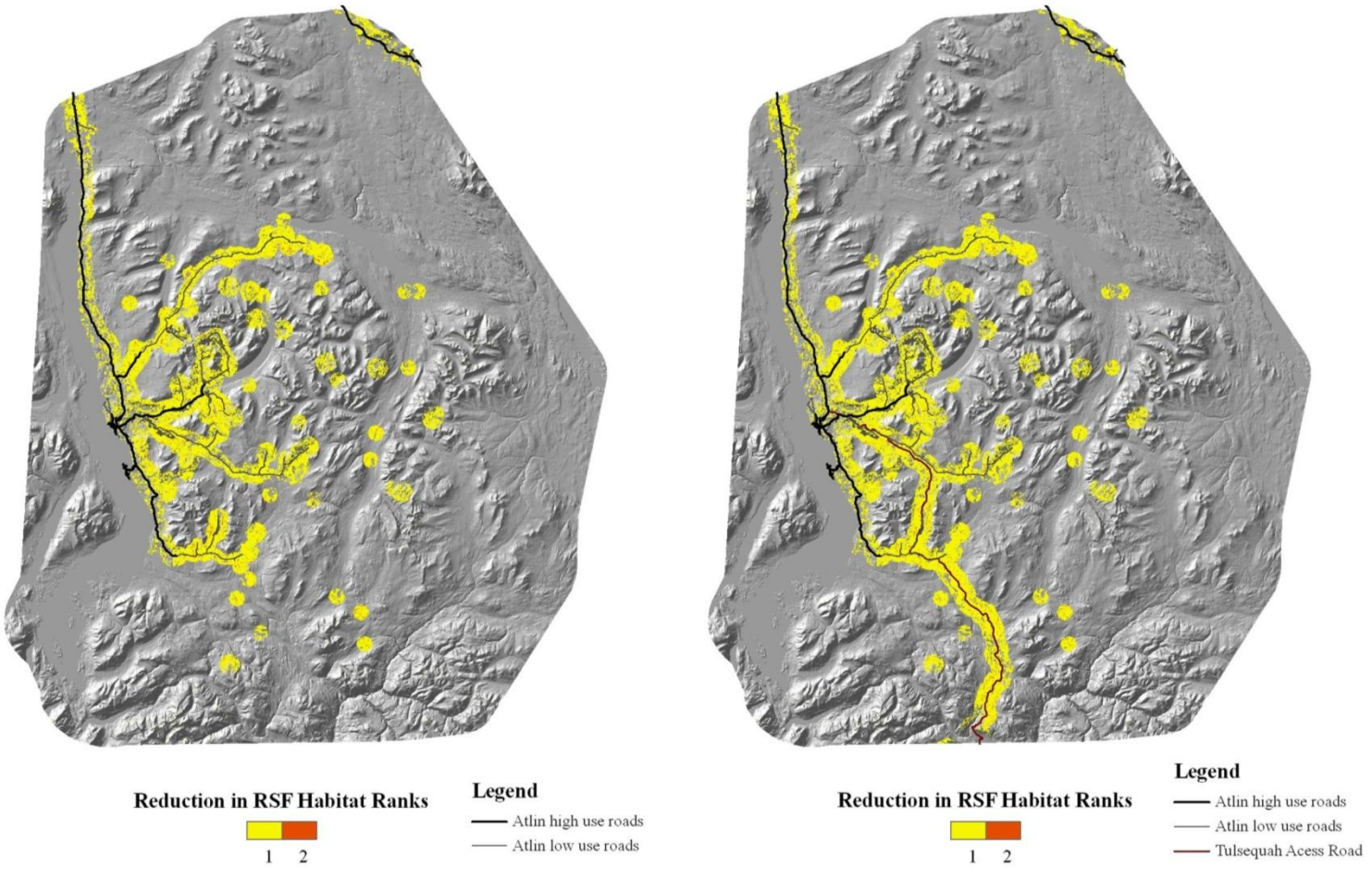


Figure 2-8. The reduction in habitat ranks between summer second-order potential and realized habitat (left) and potential and future habitat (right). Orange indicates the loss of 2 habitat ranks in that cell. The reduction in rank was used to determine the area (km^2) in each habitat rank category that was lost due to the cumulative effect of existing and future human developments on the landscape.

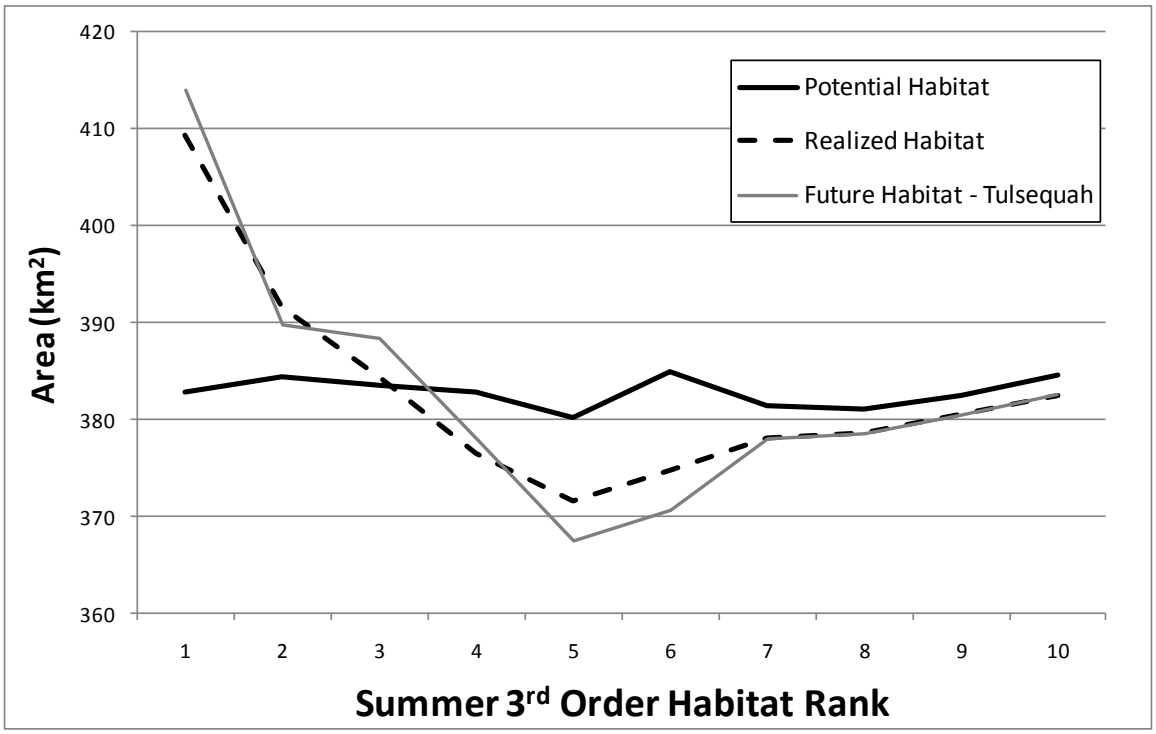


Figure 2- 9. Habitat loss associated with the summer avoidance of human developments at the third-order scale for the Atlin northern mountain woodland caribou herd in northern British Columbia, 2000-2002. The difference between potential and realized habitat ranks 8-10 can be considered the amount of high quality habitat that was lost due to current human development (6.4 km^2). The difference between realized and future habitat ranks 5-10 can be considered the amount of high and medium quality habitat that is lost due to the development of two new mines (8.3 km^2). Total study area size was 3,828 km^2 at third-order).

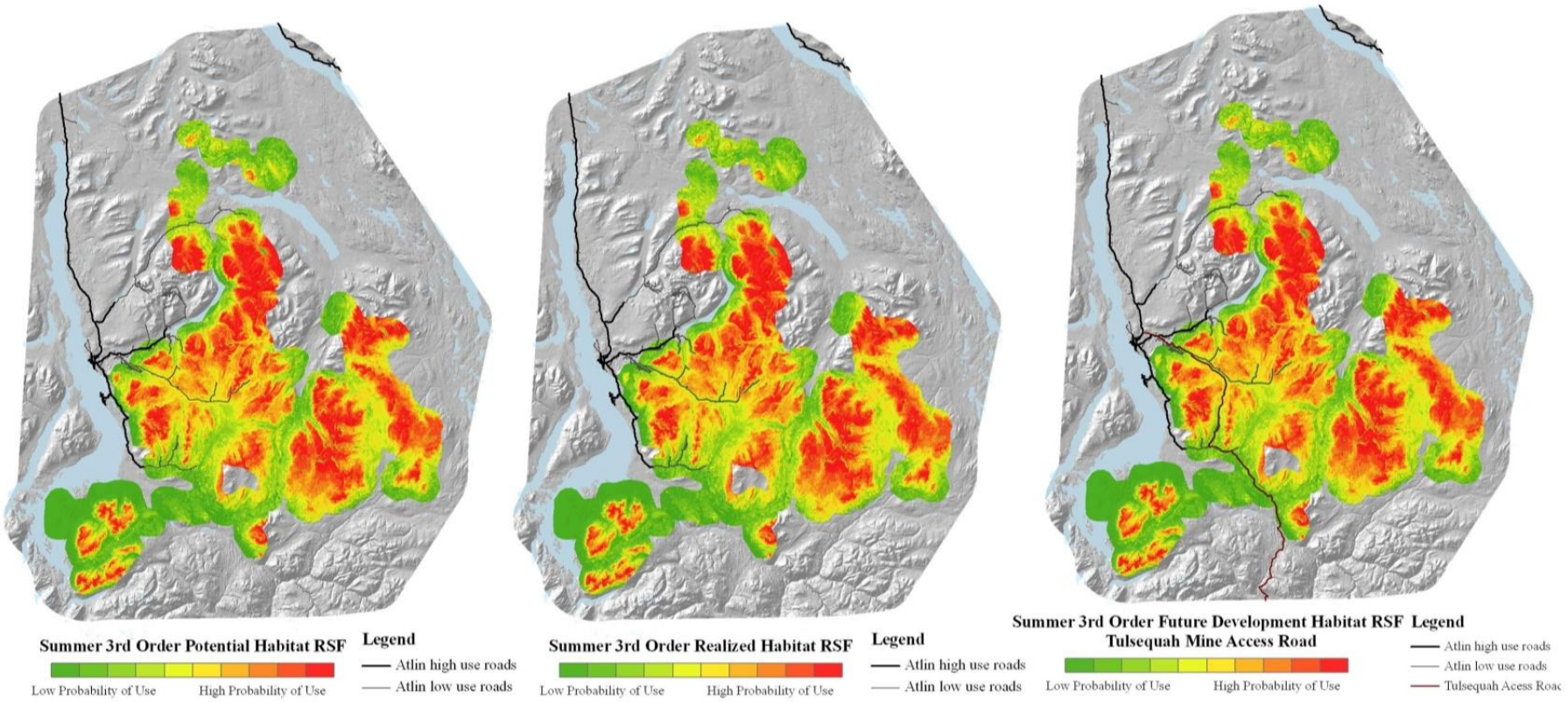


Figure 2-10. Third-order summer resource selection function maps of the potential (left) realized (middle) and future development (right) habitat of the Atlin herd of woodland caribou in northern British Columbia, Canada. The relative probability of selection is scaled between low (green) and high (red). The future development scenario that is mapped is the addition of the Tulsequah mine access road. Selection is mapped within 2.7 km of used locations (the 95th percentile of movement distance).

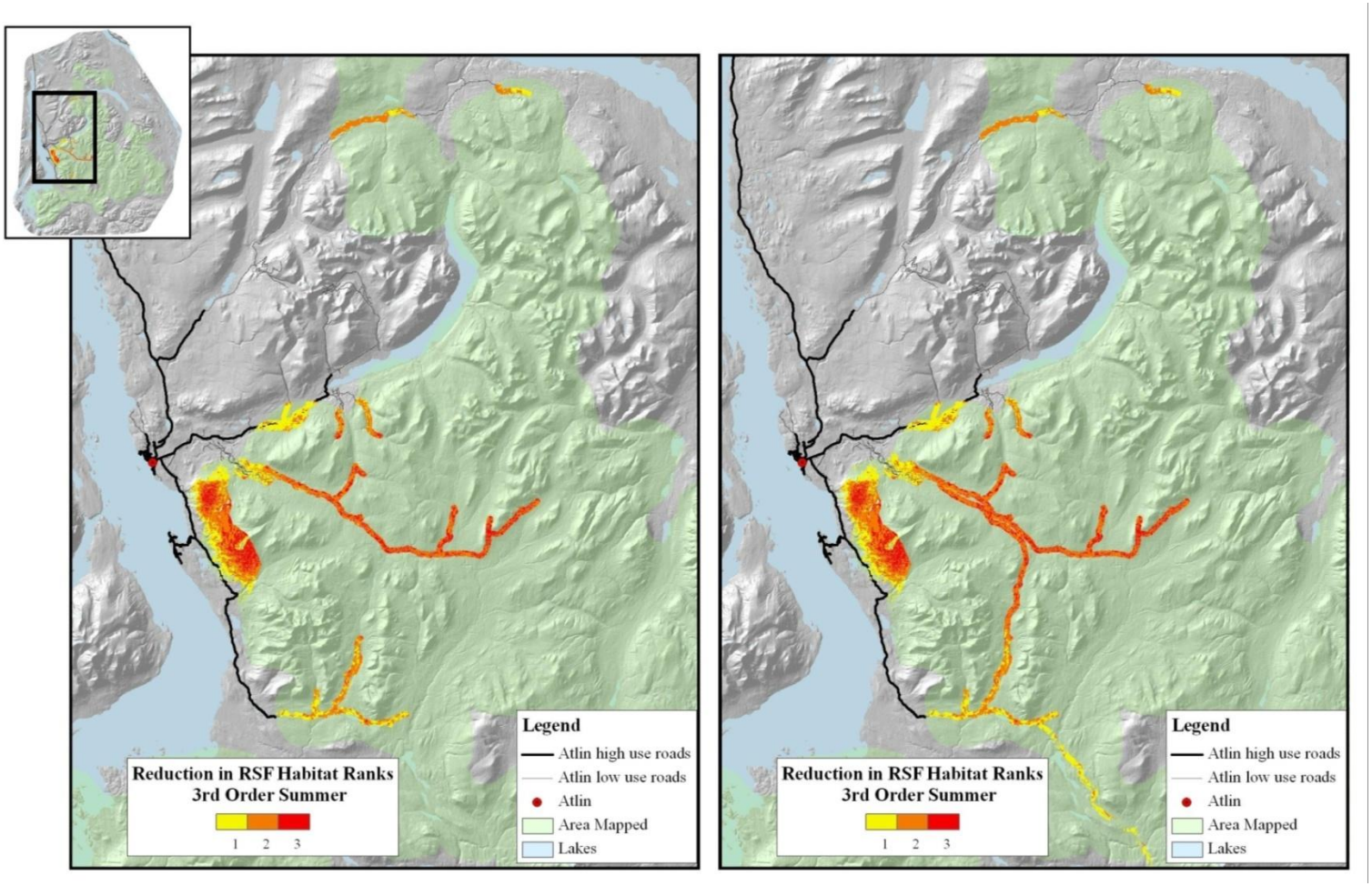


Figure 2-11. The reduction in habitat ranks between summer third-order potential and realized habitat (left) and potential and future habitat (right). Red indicates the loss of 3 habitat ranks in that cell (30x30m). The reduction in rank was used to determine the area (km^2) in each habitat rank category that was lost due to the cumulative effect of existing and future human developments on the landscape. The future development scenario that is mapped is the addition of the Tulsequah mine access road.

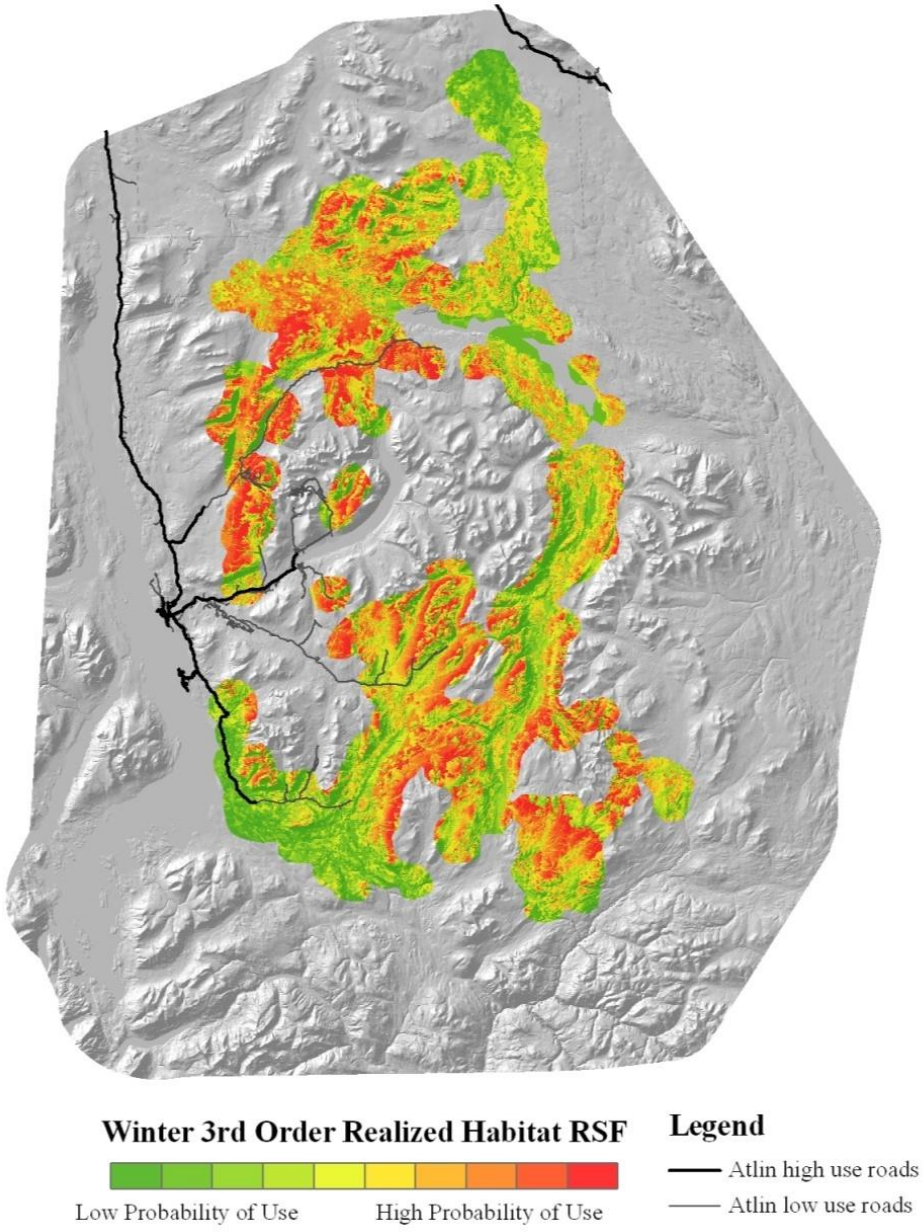


Figure 2- 12. Winter resource selection function predictions of the realized habitat along movement paths within the home range (third-order scale) of the Atlin herd of woodland caribou in northern British Columbia, Canada. The relative probability of selection is scaled between low (green) and high (red). Selection is mapped within 2 km of used locations (the 95th percentile of movement distance).

CHAPTER 3: A COMPARISON OF TRADITIONAL ECOLOGICAL KNOWLEDGE AND WESTERN SCIENCE WOODLAND CARIBOU HABITAT MODELING APPROACHES

INTRODUCTION

Conservation efforts across the world often attempt to mitigate environmental impacts in a reactionary fashion (Ludwig et al. 1993). This approach can result in ineffective single-species conservation and unsustainable ecosystem management (Frissell and Bayles 1996, Davis and Ruddle 2010). Comprehensive approaches to environmental impact studies are rare and short, small-scale studies common to Western science, often fail to provide management tools that can mitigate ecosystem degradation or reverse endangered species decline (Sinclair and Byrom 2006). The failure of current approaches to conservation and management highlights the need to seek alternative sources of information that could improve understanding of ecosystem dynamics, increase efficiency of management decisions, and enhance the validity and robustness of ecological inferences (Manseau et al. 2005, Houde 2007, Jacqmain et al. 2008). Local people often have intimate knowledge about natural systems and can contribute significant insights to the sustainable management of resources. In return, these contributions can empower local people by acknowledging the value of their expertise and by increasing their ability to influence decisions that affect their community, culture, and lifestyle (Manseau et al. 2005).

Traditional ecological knowledge (TEK) is an important source of information that is especially pertinent in northern ecosystems that frequently lack long-term ecological data used to inform management decisions (Gilchrist et al. 2005). Ecological knowledge was first introduced in anthropology and focused on the study of relationships between features of the environment and cultural traits (Orlove 1980, Berkes 1999). Traditional ecological knowledge represents diverse content to different people (Berkes et al. 2000, Huntington 2000, Davis and Ruddle 2010), a characteristic that makes defining TEK problematic. The complex, culturally dynamic processes the build TEK can be easily misrepresented (Davis and Ruddle 2010), however, it is generally agreed

that TEK represents an inherent understanding of the environment that comes from a deep historical continuity in resource use in a particular place (Berkes 1999). In this context, traditional does not specifically refer to oral history, but rather knowledge that arises from a collection of direct experiences in a particular environment (Usher 2000, Davis and Ruddle 2010). Aboriginal people often define TEK as a way of life that encompasses all parts and experiences with the environment (McGregor 2004).

Both TEK and Western science are knowledge systems based on empirical insights about the world attained through observation and experience (Davis and Ruddle 2010). Both are valid but inherently different ways of understanding, and both are biased by assumptions inherent to their culture of origin (Agrawal 1995, Brook and McLachlan 2005). Recent literature reviews have called for the need to critically evaluate TEK to assess its appropriate role in resource management (Davis and Ruddle 2010). We recognize that TEK as a distinct form of knowledge that should be evaluated equally with other categories of knowledge such as history and ecology (Schramm 2005). However, as pointed out by Davis and Ruddle (2010), Western science is the current dominant paradigm of European-descendent cultures that arose from a European philosophical and cultural context (Pierotti and Wildcat 2000). Evaluating TEK within a context understandable to Western science can encourage the incorporation and use of TEK. Through respectful and honest comparisons, TEK has the potential to corroborate and increase the validity of Western science, and vice versa, thus improving the overall goal of conservation and sustainable management of resources and wildlife.

Incorporating TEK into modern scientific resource management has the potential to complement and enhance Western science in several ways (Pierotti and Wildcat 2000, Moller et al. 2004, Jacqmain et al. 2008). First, the population-level inference that is associated with TEK can strengthen wildlife studies that are typically limited to small samples that may not be representative of the entire population (Doswald et al. 2007). Second, TEK can supplement a crucial weakness in ecology; the lack of long-term studies (Strayer et al. 1986, Carpenter 2002, Belovsky et al. 2004). Long-term observations are essential to the understanding of extreme events and adaptive habitat selection strategies (Riedlinger and Berkes 2001, Carpenter 2002). Third, TEK can be used to identify baseline conditions because it has the potential to incorporate information

prior to modern land use practices (Freeman 1992, Menzies and Butler 2006). Knowledge of ecological baseline conditions facilitates the development of recovery goals (Sinclair 1998, Manseau et al. 2005, Sinclair and Byrom 2006), and is useful to compare against current or future habitat changes (Turner et al. 2000, Nichols et al. 2004). Finally, TEK can provide an alternative to ecological research by offering high quality information without devoting time to costly or impractical ecological research (Johnson et al. 2002a).

The conservation and recovery of woodland caribou (*Rangifer tarandus caribou*) is an important public conservation priority in Canada that would benefit from the incorporation of TEK. Southern mountain and boreal woodland caribou ecotypes were federally listed as threatened in 2000 by the Committee on the Status for Endangered Species in Canada and a federal recovery plan was approved in 2004. Under the Species at Risk Act (SARA), recovery occurs through the identification and protection of critical habitat. Many Canadian environmental policies, including SARA, require that TEK be incorporated into resource management when relevant and available (Usher 2000). Therefore, there is a growing need across Canada for an effective approach to unite TEK with Western science to utilize information about caribou habitat selection that would otherwise be overlooked. The use of TEK has the potential to aid the eventual identification of critical habitat and thereby assist caribou recovery.

There are many challenges to identifying critical habitat, but the first step is to understand general habitat requirements (Environment Canada 2008). Selection is the process by which an animal chooses habitat (Johnson 1980), and understanding selection can provide information relevant to managers and recovery plans. Habitat selection studies relate the occurrence of species to environmental variables (Hirzel and Le Ley 2008) and can be based on empirical data, expert knowledge, or literature reviews (Boyce et al. 2002a). For example, resource selection functions (RSF) use a statistically rigorous framework to measure current (realized) habitat selection by examining use or avoidance of a resource relative to its availability (Manly et al. 2002). Resource selection functions can also be used to generate models of potential habitat that lack spatial constraints of development (Pulliam 2000, Soberón 2007, Hirzel and Le Ley 2008). The relationship between potential and realized habitat can be used to quantify the reduction in habitat due to the indirect avoidance of existing human developments (Johnson et al. 2005). In this

way, RSF are powerful tools for predicting animal occurrence; however, they are limited by the availability and spatio-temporal scales of data from observations of animals. Habitat suitability index (HSI) models, on the other hand, predict habitat quality using expert opinion (United States Fish and Wildlife Service 1981). Traditional ecological knowledge is a form of expert opinion that has the potential to be easily integrated into TEK-based HSI models. While the use of qualitative information from expert opinion in statistical models has been criticized (Pearce et al. 2001), HSI models can inform decisions when statistical limitations result from nonexistent, incomplete, or biased empirical data (Johnson and Gillingham 2004, Doswald et al. 2007).

We attempt to understand the strengths and weakness of Western scientific and TEK approaches to modeling caribou habitat to aid the management and conservation of northern mountain woodland caribou. The northern mountain woodland caribou ecotype occurs throughout the Yukon, Northwest Territories and northwestern British Columbia (BC). While this ecotypes has not undergone the widespread and dramatic declines experienced by the southern mountain and boreal ecotypes, there is increasing concern about the status of northern mountain populations (Northern Mountain Caribou Management Planning Team 2009). Human overharvest, habitat loss and fragmentation from forestry and energy development, human-induced changes to predator-prey communities, and proliferation of road and snowmobile networks prompted SARA to list northern mountain woodland caribou as a species of special concern in 2004 (Kinley and Apps 2001, Thomas and Gray 2002, Seip et al. 2007).

The range of northern mountain woodland caribou includes the traditional territory boundaries of 33 First Nations (Northern Mountain Caribou Management Planning Team 2009). The importance of caribou in culture and natural resource use by aboriginal people makes First Nation involvement an important component of caribou management and recovery planning (Manseau et al. 2005, Houde 2007). For example, in the northwestern corner of BC, within the traditional territory of the Taku River Tlingit First Nation (TRTFN), the Atlin northern mountain woodland caribou herd has experienced low calf recruitment and is likely in decline. Joint planning by the governments of BC and the TRTFN was recently completed to address harvest management of the herd (Taku River First Nation and British Columbia 2010). Recovery

plans and management agreements require collaborative approaches to negotiate complex political dynamics, increase the validity of ecological insights, aid in effective management, and enhance equity in decision-making (Houde 2007).

Our objectives were to first test how well TEK and Western science habitat models predict current northern mountain woodland caribou observations from very high frequency (VHF) and global positioning system (GPS) collared caribou. By using withheld location data, we test the validity of both models to spatially predict the occurrence of caribou in the study area. Next, to understand differences in predictive capacity, we compared the predictions of TEK and Western science habitat modeling approaches. Resource selection functions have the ability to evaluate habitat selection at multiple spatial scales, from landscape level studies that span close to 200,000 km^2 (Johnson et al. 2005) to small scale inferences of individual movements (Compton et al. 2002). Many studies have attributed a long temporal but small spatial scale to ecological information collected from TEK (Usher 2000, Moller et al. 2004, Fraser et al. 2006, Rist et al. 2010), though there have been few explicit tests of this (but see: Gagnon and Berteaux 2009). We test the hypothesis that TEK provides information at the landscape scale by comparing habitat models generated with TEK to RSF models developed at Johnson's (1980) second-order (landscape) and third-order (within home range) scales (Manseau et al. 2005).

METHODS

STUDY AREA

This study focused on a 11,594 km^2 area of the Atlin northern mountain woodland caribou herd's home range between Atlin and Teslin Lakes along the Yukon-BC border (Figure 2-2). The study area occurred within the 48,000 km^2 traditional territory of the TRTFN in the Skeena region of northwest BC. This region is part of the boreal mountains and plateaus ecoregion which covers northwestern BC and southern portions of the Yukon Territory (Environment Canada 2005). Mountain ranges with high peaks (2000 m), broad plateaus and wide valleys (660 m) characterize this ecozone. Boreal forests include open lodgepole pine (*Pinus contorta latifolia*), subalpine fir (*Abies lasiocarpa*) and white spruce (*Picea glauca*). Mid-elevations transition into krummholz where thick

knee high spreads of willow (*Salix* spp.) and scrub birch (*Betula glandulosa*) dominate. Alpine habitats (above 1500 m) consist of extensive areas of rolling alpine tundra characterized by sedge and altai fescue (*Festuca altaica*). Valley bottoms are comprised of deciduous stands of trembling aspen (*Populus tremuloides*), black cottonwood (*Populus balsamifera trichocarpa*), alder (*Alnus tenuifolia*) and willow. Other ungulates include moose *(Alces alces)* in valley bottoms, and mountain goats (*Oreamnos americanu*) and Stone's sheep (*Ovis dalli stonei)* in alpine habitats. Grizzly bears (*Ursus arctos*), black bears (*Ursus americanus*), wolverines (*Gulo gulo*), wolves *(Canis lupus)* and lynx (*Lynx canadensis*) comprise the mammalian predator community.

Historically, tens of thousands of Tlingit maintained camps and villages from Atlin Lake to the lower Taku River near Juneau, Alaska (McClellan 1981). During the Klondike gold rush of 1898, the Tlingit village of Atlin (59° 35' N, 133° 40' W) was populated by over 10,000 miners. Today Atlin has approximately 350 residents including roughly 130 TRTFN members that reside in town and the nearby Indian Reserve at Five Mile Point and make up one third of the official members of the TRTFN (http://www.gov.bc.ca/arr/). Atlin is connected to the Alaska Highway by one road, HWY-7. While most of the study area remains roadless, extensive dirt roads and ATV trail systems connect local logging and placer and hardrock mines. The high mineral potential in the region makes the development of large-scale mining operations likely in the future. Thus, efforts to understand potential environmental impacts of development are needed (Chapter 2).

Caribou have always been a culturally important source of meat and other animal products for the TRTFN, and TEK indicates that the herd once numbered in the tens of thousands (Heinemeyer et al. 2003). As caribou numbers declined in the early 20th century with the advent of firearms (Spalding 2000), many First Nation hunters switched to moose as a primary game species (Taku River First Nation and British Columbia 2010). In the early 1990s, concerns for population declines of the Atlin caribou herd and the Carcross-Squanga and Ibex herds (collectively known as the Southern Lakes population) led many First Nation hunters to reduce or eliminate their harvest of caribou (Farnell 2009). Monitoring efforts indicate that the two Yukon herds appear to be recovering, while aerial surveys indicate that the Atlin herd has maintained a stable or

decreasing population with a low calf recruitment of 22.5 calves:100 cows (Bergerud and Elliott 1998, Taku River Tlingit First Nation and British Columbia 2010).

ANIMAL CAPTURE

We developed RSF models from caribou monitored in the Atlin herd with GPS collars (GPS 2000, LOTEK, Aurora, ON) between December 1999 and March 2001 by the Ministry of Water, Land, and Air Protection of British Columbia (see timeline in Appendix A, Figure A-1, Diemert 2001). Caribou were captured by helicopter net-gunning according to Wildlife Radio-Telemetry, Standards for Components of BC's Biodiversity No. 5, RIC 1998. Global positioning system collars were scheduled to attempt a location every 4 hours. Model predictions were tested with the independent validation set of VHF telemetry collared animals. Seasonal VHF locations were collected from December 1999 to March 2003 from fixed-wing aircraft on a monthly schedule.

RESOURCE SELECTION FUNCTIONS

We used previously developed caribou RSF models (Chapter 2) to compare to TEK-based HSI models. We developed RSF models with a use-availability design by comparing resource covariates at used GPS locations to random available locations (Manly et al. 2002). Models were developed at the second- (landscape) and third-order (within home range) scales during winter (15 Nov – 15 May) and summer (16 May – 14 Nov). Seasons were defined based on shifts in behavior and use of different elevations by caribou. We evaluated selection at the second-order scale with generalized linear mixed models (GLMM) with a random intercept for each animal to account for unbalanced sample sizes between individual caribou and temporal and spatial autocorrelation (Gillies et al. 2006). At the third-order scale, we used a matched-case control logistic regression to estimate the relative probability of caribou selection from one time step to the next (Compton et al. 2002). Models were based on resource covariates that influence caribou resource selection. Human covariates were included in the models as a cumulative zone of influence (ZOI) buffer, that varied in extent around different human development types and between seasons. This ZOI represented the biological level of avoidance that was observed in caribou from the Atlin herd. The seasonal RSFs that included the ZOI were considered realized habitat. To model potential habitat, or the habitat available to

caribou when not constrained by avoidance of human developments (Figure 2-1), we generated a RSF without the ZOI and spatially mapped the probability of use in ArcGIS 9.3.1. (ESRI, Redlands, CA).

TEK Habitat Suitability Index Models

We conducted interviews with TRTFN members in the winter and spring of 2000 and 2001 with permission from and in collaboration with the TRTFN. Participants were selected by members of the band and were regarded as expert hunters, gatherers, or community elders. A suite of questions about cultural practices and knowledge specific to numerous animal species were used to guide semi-directive interviews (Appendix B, Huntington 1998). Interview length depended on the knowledge of the participant, varying from an hour to several days. Questions about seasonal use and food resources of key species were expanded on during interviews. Participants were encouraged to outline key areas and animal locations on maps. All interviews were voice recorded and later transcribed. Information relevant to caribou resource selection was extracted from interviews and summarized in tables (Appendix B).

Habitat associations, seasonal foraging strategies, distributions, and the availability of resources described in interviews were linked with the same spatial resource covariates that were used to generate the RSF models. These variables were used to create rule based ranked HSI models (Gontier et al. 2010) for summer (June-November) and winter (December -May) to match with seasonal periods developed in the RSF models. The relative quality of habitat was based on an index value on a scale from 10 (highest value) to 1 (lowest value). Variables associated with a high number of respondents reporting similar observations were given the highest ranks. TRTFN members were not interviewed about human activities, thus, human developments were not incorporated into the final prediction of habitat quality in the HSI models.

Model Variables

Vegetation community data was classified with Landsat TM satellite imagery (Chapter 4) into 13 landcover types (Table 2-2, classification success of the landcover model was 75%). Covariates such as elevation (m), slope, hillshade and aspect (30 m^2 resolution) were extracted from the TRIM digital elevation model (DEM) using Spatial

Analyst for ArcGIS 9.3.1. Percent snow cover was generated from 8-day composites of maximum snow extent maps at 500 m^2 resolution produced by NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) satellites (Hall et al. 2000). To represent alpine areas where lasting snow patches were likely to occur, we divided the number of days snow occupied a cell by the number of days in the period to generate spatial models of percent snow cover for May and June 2000 to 2005. Resource selection function models also incorporated percent snow cover across the winter and summer seasons, and information from a Normalized Difference Vegetation Index (NDVI) modeled by averaging 16-day composite of the at a 250 m^2 resolution from MODIS satellites across seasons (Huete et al. 2002, Pettorelli et al. 2005).

MODEL EVALUATIONS AND COMPARISONS

All habitat selection models attempt to predict habitat quality (Mladenoff et al. 1995) and/or species occurrence (Fortin et al. 2008). Given the application of such models to management and policy, testing their ability to make reliable predictions about animal locations is essential (Gude et al. 2009). When independent data are unavailable there are numerous methods of internal validation to test the reliability of model predictions (e.g., k-folds cross validation, Boyce et al. 2002a, Johnson et al. 2006, Gude et al. 2009). However, the utility of models often depends on their ability to predict external locations not used in model development (Wiens et al. 2008). External model evaluation assesses models with data that were not involved in the model-building process and is the best test of model robustness (Hosmer and Lemeshow 2000, Boyce et al. 2002a).

To evaluate the predictive ability of each habitat model we used withheld VHF data (that was not used in RSF model development) to validate the TEK-based HSI and RSF models. We also used the GPS data that was used to build the RSFs to validate TEK models. For each evaluation, we intersected the validation set of caribou locations with spatial predictions of the model (e.g., maps) and calculated the number of locations that fell within each of the 10 habitat rank classes normalized by the area of that class. Adjusting each class by area controlled for differences in the predicted area of each habitat rank class between models (Boyce et al. 2002a, Johnson and Gillingham 2005). We used a Spearman's rank correlation (r_s) to test how well the habitat quality rank class

correlated to the frequency of caribou locations. We expected models with high predictive ability to have a greater number of locations in high quality habitat (Boyce et al. 2002a).

To test the hypotheses that TEK-based HSI models most closely resemble second-order habitat, we compared the habitat quality rank of all RSF models (winter second-order potential and realized, winter third-order realized and summer second- and third-order potential and realized) with TEK-based seasonal models by generating 10,000 random points across the study area and intersected the points with all models. We evaluated the spatial discrepancies by using a weighted Kappa statistic and Spearman's rank correlation. Kappa statistics can be used to evaluate the amount agreement in habitat quality ranks at random locations between pairs of maps (Monserud and Leemans 1992). The Kappa index value reflects the difference between the actual agreement and the amount of agreement that would occur by chance. A value of 1 indicates perfect agreement while a value of 0 indicates that the observed agreement is approximately equal to what would be expected by chance (Monserud and Leemans 1992, Johnson and Gillingham 2005). A non-weighted Kappa statistic does not take into account the degree of difference between paired locations and counts all disagreements (even if by only one rank) as total disagreements. A weighted Kappa allows different levels of agreement to contribute to the final value of the Kappa statistic (StataCorp 2007). Therefore, we used a standard weighting option "w" in STATA 11.0 (StataCorp 2007) where equal ranks receive a weight of 1, a difference of one habitat rank received a weight of 0.89, a difference of 2 ranks received 0.78, etc. We also calculated the Spearman's rank correlation which indicates the differences in ranks between the 10 habitat rank classes.

In a second series of comparisons, we simplified the ranks of all models to 3 habitat rank classes that represented high, medium and low quality habitat. This more accurately reflected the heuristic nature of the TEK-based HSI models because the differences between ranks 8, 9 and 10 may not have replicated substantial differences in habitat quality (Johnson and Gillingham 2005). Ranking the models into 3 classes also generated approximately equal areas in each class for the TEK and RSF models. We evaluated the 3 class models with Kappa and Spearman's correlation in the same way as the 10 class comparisons. Finally, to visually examine where spatial discrepancies

occurred we subtracted the TEK models from all RSF models one at a time and mapped the difference between ranks in each cell for each pair.

RESULTS

Global positioning system radio-collars were placed on 8 female and 2 male caribou and VHF telemetry collars were placed on 13 female and 4 male caribou. We obtained 16,270 GPS locations and 661 VHF locations from December 1999 and March 2003 (Table 2-1). Seasonally, there were 215 summer VHF locations (170 of which fell within the third-order study area perimeter) and 446 winter VHF locations (365 of which fell within the third-order study area).

RESOURCE SELECTION FUNCTION MODELS

At the second-order scale caribou showed significant avoidance of both the summer and winter human ZOI buffers which were included in the realized habitat RSFs. In Chapter 2 we found that in winter there was a 7.9% difference in high quality habitat between the realized and potential maps and a 1.7% difference in summer. In winter, at the second-order, caribou selected intermediate elevations (1,179 m) and selected for lichen-lodgepole pine complexes, spruce-fir forests, and lower elevation river valleys comprised of *Salix* spp. Caribou avoided krummholz, rock, burned lodgepole pine, alpine tundra, water and steep slopes (Table 2-5). Caribou were associated with intermediate NDVI values, areas with approximately 60% winter snowcover and slopes with high sun exposure. At the third-order scale in winter, the human ZOI buffer was not significant, thus the potential and realized third order winter RSFs were the same. Because inferences of resource selection at the third-order represent where caribou choose to move at the next time step, we mapped selection within a 2 km buffer (95^{th} percentile of movement distance) around used locations. Within this limited region, caribou occurrence was positively related to lichen-lodgepole pine forests, spruce-fir forests, mixed wood stands, high elevation, and low slopes. Caribou demonstrated avoidance of alpine tundra and areas with high percent winter snow cover.

Conversely, in the summer, caribou habitat selection shifted to higher elevations (1,363 m) and at the second-order, caribou displayed strong selection for krummholz, alpine shrubland, alpine tundra, rock, slopes with high sun exposure, and areas that had

high percent snow cover in winter. Caribou used lodgepole pine and mixed conifer forests less than available which also resulted in avoidance of high NDVI values. Finally, caribou were negatively associated with water and steep slopes. At the third-order caribou avoided the summer third-order ZOI buffer. Selection was mapped within a 2.7 km buffer (95th percentile of movement distance) around used locations. Within this extent, caribou exhibited selection for alpine tundra, and high elevations. The probability of occurrence also increased in mixed wood forests, areas of high percent snow cover during the previous winter, high NDVI values and low slopes with high sun exposure. Caribou generally avoided water, mixed conifer forests, and areas with high percent snow cover during the summer (Table 2-6).

TEK Habitat Suitability Index Models

There was strong consensus between the 8 informants about seasonal caribou habitat use. In winter, TRTFN members indicated that caribou selected for low elevation forests, especially mature lodgepole pine stands with high lichen ground cover. They also indicated that caribou used low elevation valleys in river bottoms and open windswept slopes in the alpine depending on snow conditions. Low elevation lakes were also identified as important escape terrain from predators and were thought to be used by caribou in winter as mineral licks (Figure 3-1). The HSI rules used to rank the variables are shown in Table 3-1. To generate a summer model that would match the seasonal predictions of the summer RSF (16 May-14 Nov) we included information from TRTFN members about caribou habitat use in spring, summer and fall. Interviewees reported that caribou used predominately high elevation alpine environments during the entire period and could often be found on remnant snow patches to escape insects. They also indicated that caribou were wide-ranging and used mountain sides and slopes where they foraged on grass, willow, and lichen (Figure 3-2, Table 3-2).

Model Comparison and Evaluation

All summer RSF models had high predictive capacity and reliably predicted the external caribou VHF locations. The predictive capacity of the second- and third-order realized summer RSFs were consistently high (r_s = 0.994 and 0.967) and marginally better at predicting VHF caribou than the second- and third-order potential RSFs (r_s =

0.921 and 0.964). We observed similarly high predictive capacity in winter at the second-order (realized r_s = 0.997 and potential r_s = 0.979). However, the third-order realized RSF had the weakest correlation with the independent VHF data (r_s = 0.782). We also found that the TEK-based HSI models had high predictive performance when evaluated with all caribou location data (both GPS and VHF). The summer TEK model preformed strongly with the GPS locations (area adjusted average r_s = 0.910), though this model had relatively low predictive performance for the VHF data (r_s = 0.612). The winter TEK model performed better with the VHF data (r_s = 0.806), than with the GPS locations (r_s = 0.750), though all were above 0.7 indicating 'high accuracy' and 'useful application' models (Boyce et al. 2002a).

In general, when we compared RSF and TEK-based HSI models for the 10 class models, the Kappa statistic suggested fair (0.21-0.40) to moderate (0.41-0.60) spatial agreement between the predictions of the RSF and TEK models. During summer, the third-order RSF models had the highest relative agreement to the TEK models (Table 3-3) which was also reflected in the Spearman's rank correlations (Table 3-4). In general, the winter third-order RSF had very poor agreement with the TEK model in all comparisons.

However, there were large differences in the amount of area in each of the ten habitat rank classes between the TEK and RSF models. The RSFs were allocated with equal areas in each class. On the other hand, due to the methods used to rank the TEK models, the amount of area in each habitat rank class was not equal. For example, the TEK models allocated between 47% (summer) and 30% (winter) of the study area into class 1, and less area in the top habitat rank classes (ranks 8, 9 and 10) than the RSF models.

To standardize the amount of area in each class we reduced the number of rank classes from 10 to 3. These three classes represented high (30%), medium (30%) and low (40%) quality habitat in the study area. In all cases the spatial agreement increased (Table 3-3). Interestingly, we found that the Kappa value between the second-order summer RSF and TEK models increased the most to suggest 'substantial' spatial agreement (0.61-0.80). The 3 class comparisons indicated that second-order RSFs had higher spatial agreement with the TEK models than the third-order RSFs (Figure 3-3).

Visual inspection of the differences between the RSF and TEK maps indicated that most spatial discrepancies were a result of the RSF model predicting higher quality habitat than the TEK model. In winter, discrepancies were most apparent on north and west slopes, as well as in a large burn in the northern part of the study area (Figure 3-4). The TEK model predicted higher quality habitat in and around the town of Atlin. In summer, areas of low elevation were given higher rank by the RSF models than the TEK model (Figure 3-5).

DISCUSSION

Evaluating the predictive performance of habitat selection models with external data is the most effective way of determining the reliability of a model, and is often considered the 'gold standard' validation technique (Brooks 1997, Wiens et al. 2008). In this study, we assessed the ability of RSF and TEK-based HSI models to predict caribou locations in the study area that were not used to generate the models. We found that both techniques were robust predictors of independent caribou locations. Specifically, we determined that high frequencies of GPS and VHF caribou locations occurred within areas that the TEK models predicted as high quality habitat. This is an encouraging result that not only supports the validity of TEK-based HSI models to successfully predict caribou occurrence in our study area, but also strengthens inferences that can be made about the RSF models. The TEK model represents a long-term perspective about the habitat use of the Atlin herd of woodland caribou, while the RSF corresponds to a short-term characterization of the habitat use of 10 individual caribou. The high predictive aptitude of both models highlights the strengths and limitations of each, and provides a robust and comprehensive representation of caribou occurrence.

Other studies have also demonstrated the utility of TEK in understanding habitat selection. In northern Quebec, Jacqmain et al. (2008) found that hypotheses generated from Cree knowledge of moose-habitat relationships concurred with results of moose resource selection function models. However, their approach did not specifically test Cree habitat models, but rather used Cree hunter's knowledge to guide a Western science-based study of moose habitat selection in a collaborative manner. Our results support a growing body of research that suggest that expert-based HSI models can often be good predictors of habitat use, and can contribute important information to

conservation goals (Johnson and Gillingham 2004;2005). For example, in the Swiss Alps, Doswaled et al. (2007) found that HSI models generated with local-knowledge of game wardens predicted lynx (*Lynx lynx*) habitat use derived from telemetry data. In North Carolina, Mitchell et al. (2002) evaluated a black bear HSI model with independent location data and found that it was reliable and robust. Conversely, Johnson and Gillingham (2005) found that a HSI used to model caribou habitat in BC was a poor predictor of caribou distribution, especially when compared to RSFs and species niche models. However, the HSI model they used was designed to predict caribou occurrence across BC and was not developed based on local expert knowledge. The ability of expert-based approaches to accurately predict occurrence is clearly dependant on study specific requirements and objectives (Brooks 1997). We agree with other researchers who suggest that when data are limiting, expert HSI models can provide a fast and reliable alternative to empirical data collection (Johnson and Gillingham 2004).

Our study provided encouraging results for the collaboration of TEK and Western science habitat modeling approaches, and direct comparisons of the models indicated similarities as well as significant spatial discrepancies. Often, RSF models predicted higher quality habitat than TEK models. This could have been a result of how model habitat ranks were classified and the amount of area that fell into each of the 10 habitat classes (Johnson and Gillingham 2005). Because of the rule-based design used to develop the HSI models, creating equal area classes was difficult. One approach to deal with this potential problem is to use a simplified classification system. By classifying the models into low, medium and high quality habitat, we increased the correlation between RSF and TEK models while at the same time retaining information. Other spatial deviations could have been due to differences in the variables used to develop the models (Johnson and Gillingham 2005). The RSF models incorporated resource covariates of slope, hillshade, NDVI, and seasonal snow cover. In fact, visual inspect of the differences between habitat ranks of the winter TEK and RSF models implies that north and western slopes had high discrepancy which could be a result of the covariate for hillshade in the RSF models (Figure 3-4). We also found differences in the winter within a large historic burn. This may reflect a need to harmonize the way RSF and TEK models incorporate burns. In summer, models had relatively high spatial agreement especially in the three class model.

Most discrepancies occurred in valley bottoms. These areas were often excluded from the TEK models based on an elevational cut-off and thus received lower values than the RSF models.

Our comparisons suggest that TEK-based HSI models most closely resembled caribou habitat at larger, second-order (landscape) scales during winter. When comparing the 10 class habitat rank models for summer, the Kappa statistic and Spearman's correlation indicated that the third-order RSF models most closely resemble the TEK models. However, when simplified to 3 classes, the Kappa indicated that both winter and summer second-order RSFs were highly associated with the TEK models. The scale of a habitat study is often a reflection of the methodologies used and questions under investigation. Resource selection function models allow the researcher to investigate different scales with different statistical methods (in this case GLMM and conditional logistic regression). Gagnon and Berteaux (2009) reported that in Nunavut, Canada, TEK regarding arctic fox (*Vulpes lagopus*) feeding ecology broadened the spatial context of the scientific data (up to 23,000 km^2) but that TEK on the molting locations and migrations of greater snow goose (*Chen caerulescens atlantica*) was more similar to Western scientific research. They suggest that when scales of Western scientific and TEK-based studies differ, the two applications have the greatest potential to complement each other and provided new insights and hypotheses. In our study, the scale of TEK data may simply be a manifestation of the questions that were asked during interviews. We suggest that care be taken when developing interview questions so that if external data is available, questions can be focused on complimenting the scale of the other data.

Results of the Kappa statistic and Spearman's rank correlation indicated slightly higher spatial association between the TEK models and the potential RSFs compared to the realized RSFs, though the results were generally not significantly different. The TEK models predicted higher quality habitat than the realized RSFs surrounding the town of Atlin and high use roads. Since questions regarding human developments were not included in interviews with TRTFN members, and therefore, human influences were not included in the TEK models, this result is expected and supports the assumption that potential habitat is habitat available to caribou when not constrained by avoidance of human developments. Using TEK to develop maps of potential habitat could have

important implications in recovery planning and management by providing information about ecological baseline conditions. These comparisons suggest that TEK could be useful to identify potential habitat when interviews do not include questions about avoidance of human developments.

Our study is the first to quantitatively compare TEK-based woodland caribou habitat models with habitat models developed with Western science approaches. We suggest that the high predictive ability of both approaches, as well as numerous spatial similarities, implies that TEK is an appropriate tool that should be used to aid caribou recovery planning. The TRTFN are engaged in joint land-use planning and wildlife management planning with the provincial government and caribou habitat identification is an important conservation concern (TRTFN/BC 2008). Our results strengthen ecological inferences regarding caribou-habitat relationships within the planning area and provide additional information based on TRTFN TEK which can be used to develop land-use and caribou management plans. There is an ever-increasing need to apply similar TEK-based habitat modeling approaches to caribou herds across the boreal forest of Canada. Such TEK-based analysis could, for example, facilitate the implementation of a national recovery plan for the boreal population of woodland caribou. Within the planning region for boreal caribou there are approximately 64 herds, of which scientific data are available for only 25. In this situation, prioritizing the collection and incorporation of TEK in areas where scientific data are limited may be the most efficient way to initiate a recovery strategy.

The application of TEK in wildlife studies across Canada will provide useful insights by filling information gaps, increasing the participation of aboriginal people in resource management, and helping to encourage culturally appropriate solutions to management dilemmas (Rist et al. 2010). However, it is crucial to approach and collect TEK with respect and understanding of cultural differences and values (Brook and McLachlan 2005). There is always a risk of knowledge being taken out of context, misinterpreted, or misused (Usher 2000). TEK must be treated ethically which requires data ownership agreements and confidentiality of individuals for appropriate collaboration (Wenzel 1999). We encourage honest recognition of the inherent limitations and biases of both TEK and Western science approaches to management.

Though there are potential challenges regarding the translation of ideas and concepts between worldviews and cultures, our results suggest that both TEK and Western science can be used to facilitate a more complete and mutually affirming approach to wildlife management. A respectful partnership between TEK and Western scientific studies will increase the efficiency of conservation by highlighting the strengths and minimizing the weakness of each. The ultimate value of TEK approaches to understanding habitat dynamics and wildlife management remains in the forefront of conservation in Canada.

Table 3-1. Resource covariates used to generate habitat suitability index (HSI) models of winter habitat used by the Atlin herd of northern mountain woodland caribou in northern British Columbia. Interviews were conducted with members of the Taku River Tlingit First Nation in 2000 and 2001. Information relevant to winter caribou habitat use was extracted and used to generate HSI models with the following rules.

Interview Description	Landcover Type	Elevation	Aspect	Rank
Low elevation lakes	Lake	<1150 m	all	2
High in mountains	Alpine Tundra	>1150 m	all	2
Open, high elevation windswept slopes	Alpine Tundra, Rock, Snow	>1150 m	90-180°	3
Low elevation forest	Spruce/Fir, Mixed Conifer, Mixedwood	<1150 m	all	4
Lodgepole pine (all elevations)	LP/Lichen	>1150 m	all	5
Low elevation river valleys	Alpine Shrub, Low Valley Salix	<1150 m	all	5
Low elevation forest near lodgepole pine forest	Spruce/Fir, Mixed Conifer, Mixedwood <500 m from LP/Lichen	<1150 m	all	7
Low elevation lodgepole pine forest	LP/Lichen	<1150 m	all	9
Lakes as escape terrain	Low elevation forests (LP/Lichen, Spruce/Fir, Mixed Conifer, Mixedwood < 1150 m) and low elevation valleys (Alpine Shrub and Low Valley Salix <1150 m) < 1 km from Lake		all	add 1

Notes: Abbreviations are LP, lodgepole pine (*Pinus contorta var. latifolia*).

Table 3-2. Resource covariates used to generate habitat suitability index (HSI) models of summer (includes descriptions of spring and fall habitat use) habitat used by the Atlin herd of northern mountain woodland caribou in northern British Columbia. Interviews were conducted with members of the Taku River Tlingit First Nation in 2000 and 2001. Information relevant to summer caribou habitat use was extracted and used to generate HSI models with the following rules.

Interview Description	Landcover Type	Elevation	Aspect	Rank
Below treeline, wide-ranging	LP/Lichen	<1150 m	all	2
Mountain sides and slopes, wide ranging	Krummholz, Low Valley Salix, Alpine Shrub	<1150 m	all	3
Mountain sides and slopes, eat grass and lichen	Alpine Tundra	<1150 m	all	4
Snow to escape insects	Snow	<1150 m	all	4
Below treeline, mountain sides and slopes, wide-ranging	Low Valley Salix, LP/Lichen, Spruce/Fir, Mixed Conifer, Mixedwood	> 1150 m	all	add 1
High in mountains, graze on grass and other vegetation	Alpine Tundra, Alpine Shrub, Krummholz, Rock, Snow	> 1150 m	all	add 3
North facing slopes to escape insects on snow patches	Alpine Tundra, Alpine Shrub, Krummholz, Rock, Snow	> 1150 m	315-135°	add 2
Use last of snow to escape insects	Alpine Tundra, Alpine Shrub, Krummholz, Rock, Snow in area with > 50% snow cover for May and June (MODIS snow cover data)	all	all	add 1

Notes: Abbreviations are LP, lodgepole pine (*Pinus contorta var. latifolia*); MODIS, Moderate Resolution Imaging Spectroradiometer satellites.

Table 3-3. Weighted Kappa statistic between seasonal traditional ecological knowledge (TEK) habitat suitability index models and resource selection function (RSF) models at the second- and third-order scales as well as realized and potential habitat. Habitat quality was ranked into 10 classes in the top table and three classes in the bottom table.

Ten Ranks	Winter TEK	SE	Summer TEK	SE
Second-order Realized	0.284	0.0059	0.323	0.0051
Second-order Potential	0.292	0.0059	0.323	0.0051
Third-order Realized	-0.014	0.0130	0.517	0.0110
Third-order Potential	N/A		0.520	0.0110

Three Ranks	Winter TEK	SE	Summer TEK	SE
Second-order Realized	0.337	0.0080	0.649	0.0080
Second-order Potential	0.343	0.0080	0.649	0.0080
Third-order Realized	-0.092	0.0164	0.585	0.0135
Third-order Potential	N/A		0.592	0.0135

Table 3-4. Spearman's rank correlations between seasonal traditional ecological knowledge (TEK) habitat suitability index models and resource selection function (RSF) models at the second- and third-order scales as well as realized and potential habitat. Habitat quality was ranked into 10 classes in the top table and three classes in the bottom table.

Ten Ranks	Winter TEK	Summer TEK
Second-order Realized	0.446	0.758
Second-order Potential	0.452	0.761
Third-order Realized	-0.095	0.800
Third-order Potential	N/A	0.804

Three Ranks	Winter TEK	Summer TEK
Second-order Realized	0.469	0.744
Second-order Potential	0.472	0.746
Third-order Realized	-0.123	0.775
Third-order Potential	N/A	0.782

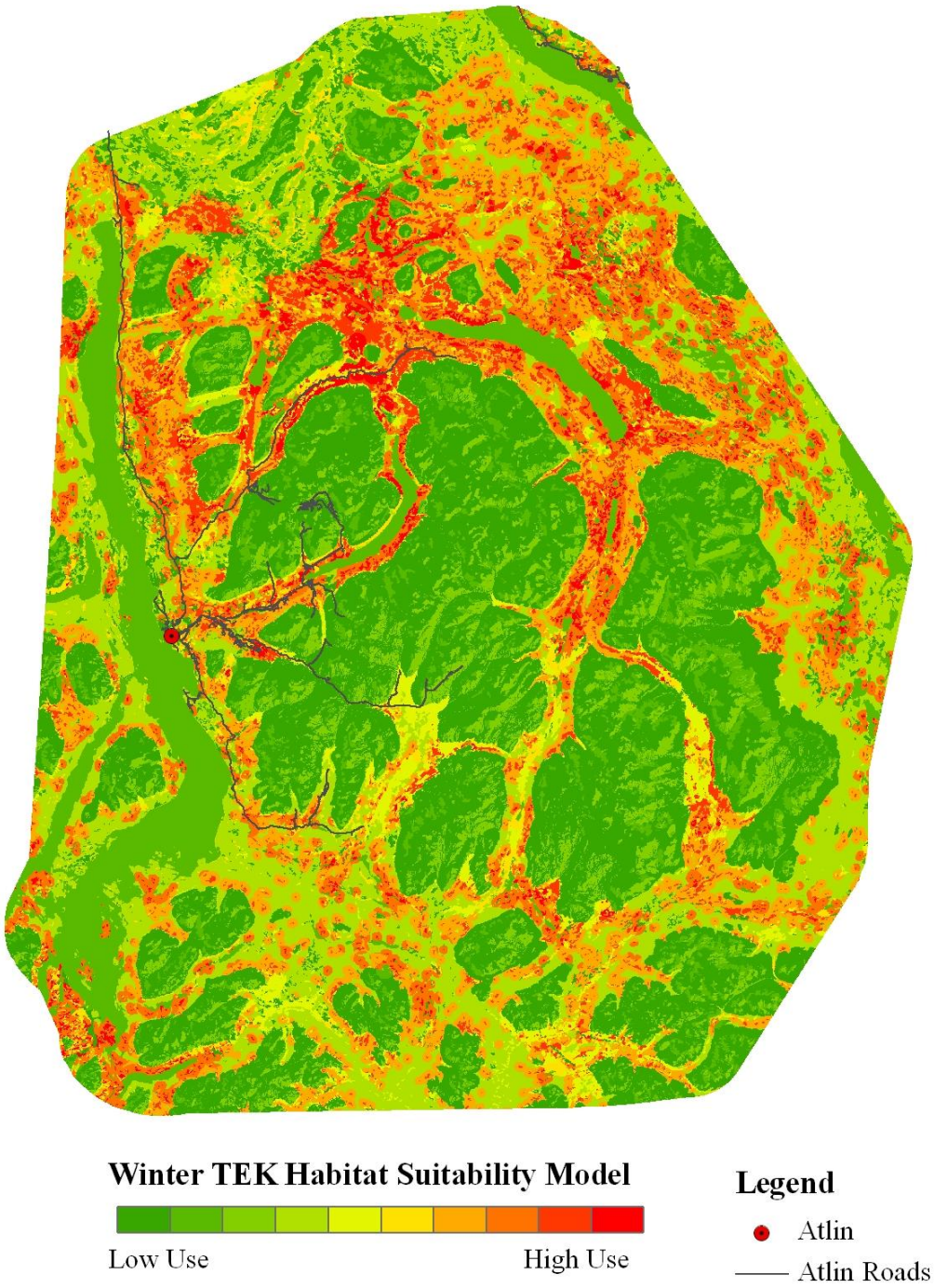


Figure 3-1. Winter habitat suitability index model map of northern woodland caribou use generated with the traditional ecological (TEK) knowledge of the Taku River Tlingit First Nation of northern British Columbia, Canada.

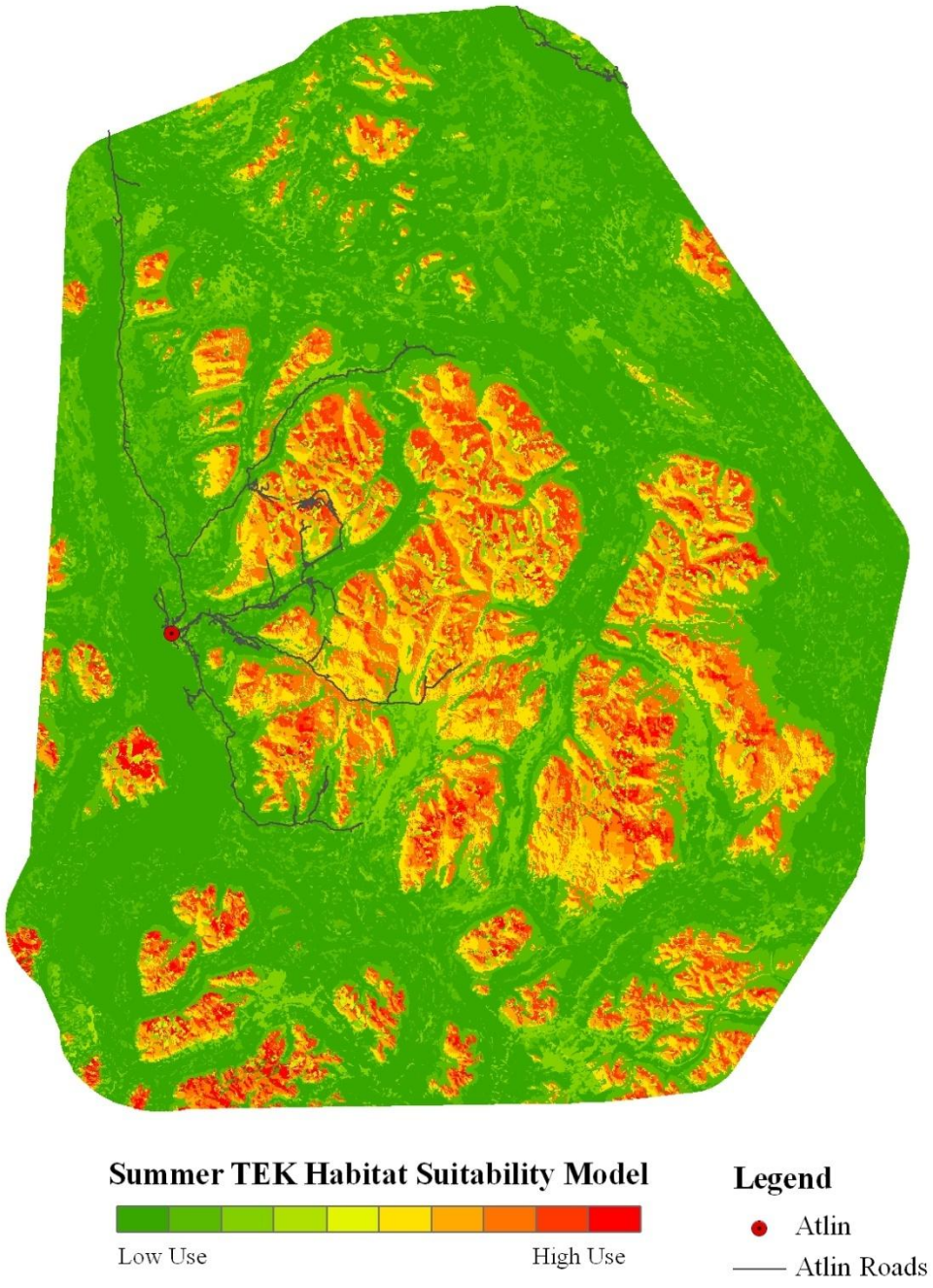


Figure 3-2. Summer habitat suitability index model map of northern woodland caribou use generated with the traditional ecological (TEK) knowledge of the Taku River Tlingit First Nation of northern British Columbia, Canada.

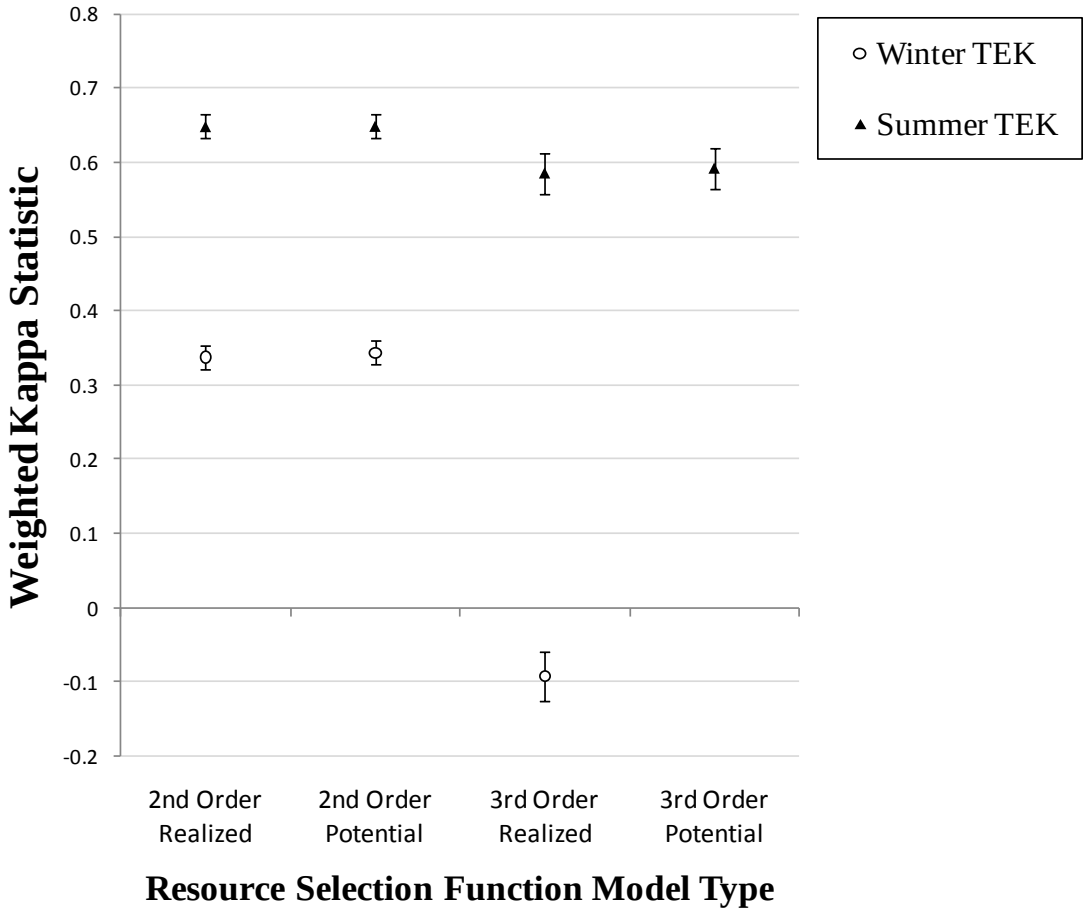


Figure 3-3. Weighted Kappa statistic between seasonal traditional ecological knowledge (TEK) habitat suitability index models and resource selection function (RSF) models at the second- and third-order scales as well as realized and potential habitat. Habitat quality was ranked into 3 classes.

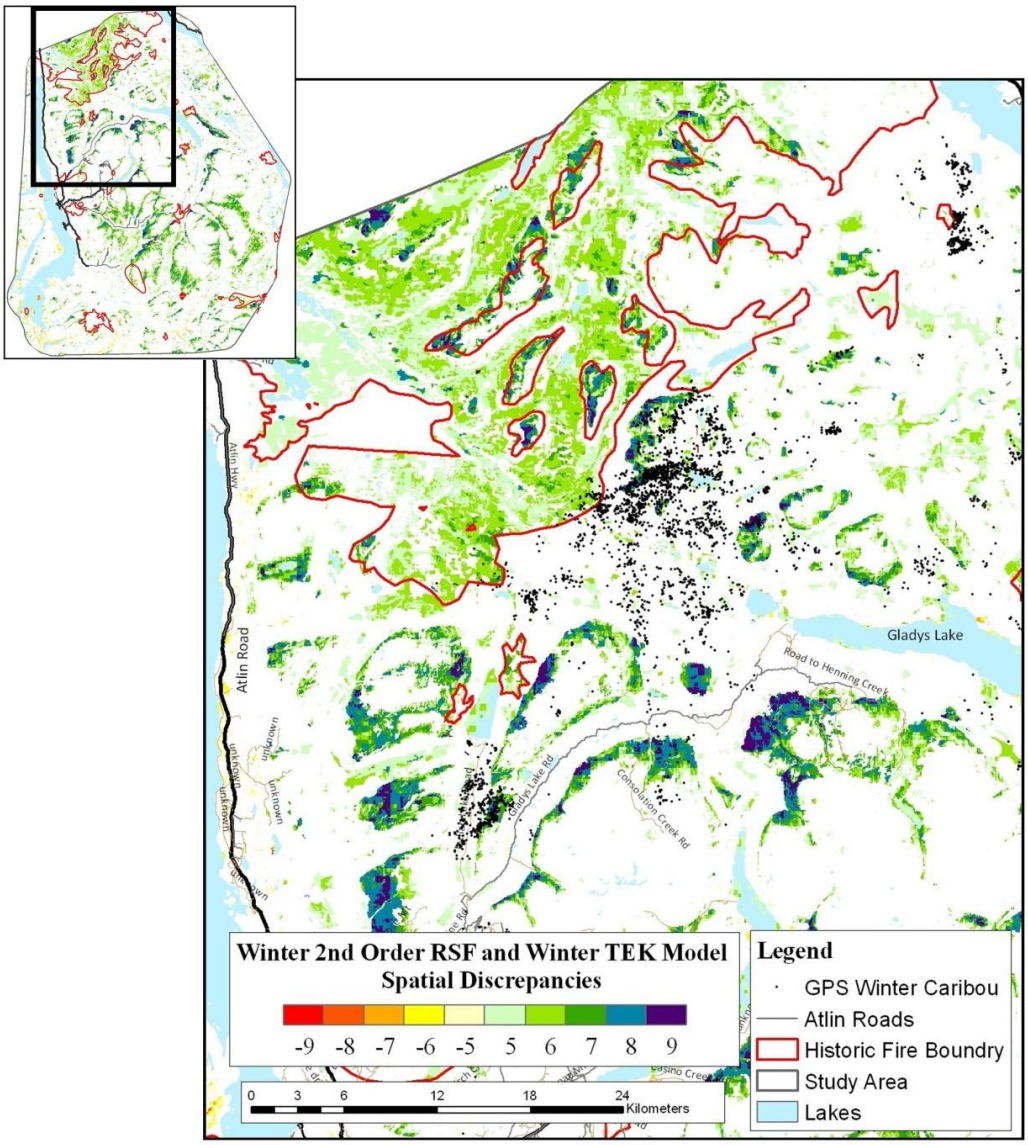


Figure 3-4. Spatial discrepancies between winter realized resource selection function (RSF) generated with spatial information from caribou locations and winter habitat suitability index model generated with the traditional ecological (TEK) knowledge of the Taku River Tlingit First Nation in northern British Columbia, Canada. Warm colors indicate areas where the TEK model predicted high caribou use and the RSF model predicted a low probability of caribou use (along the Atlin road). Cool colors indicate places where the RSF predicted a high probability of use and the TEK model predicted low caribou use. The numbers represent the difference in habitat classes. For example a positive 9 indicates that the RSF predicted a 10 and the TEK model predicted a 1. Only discrepancies of greater than 5 habitat ranks were colored. Notice the large area of discrepancy within the historic fire boundary. The RSF may have over predicted the probability of caribou use in this area.

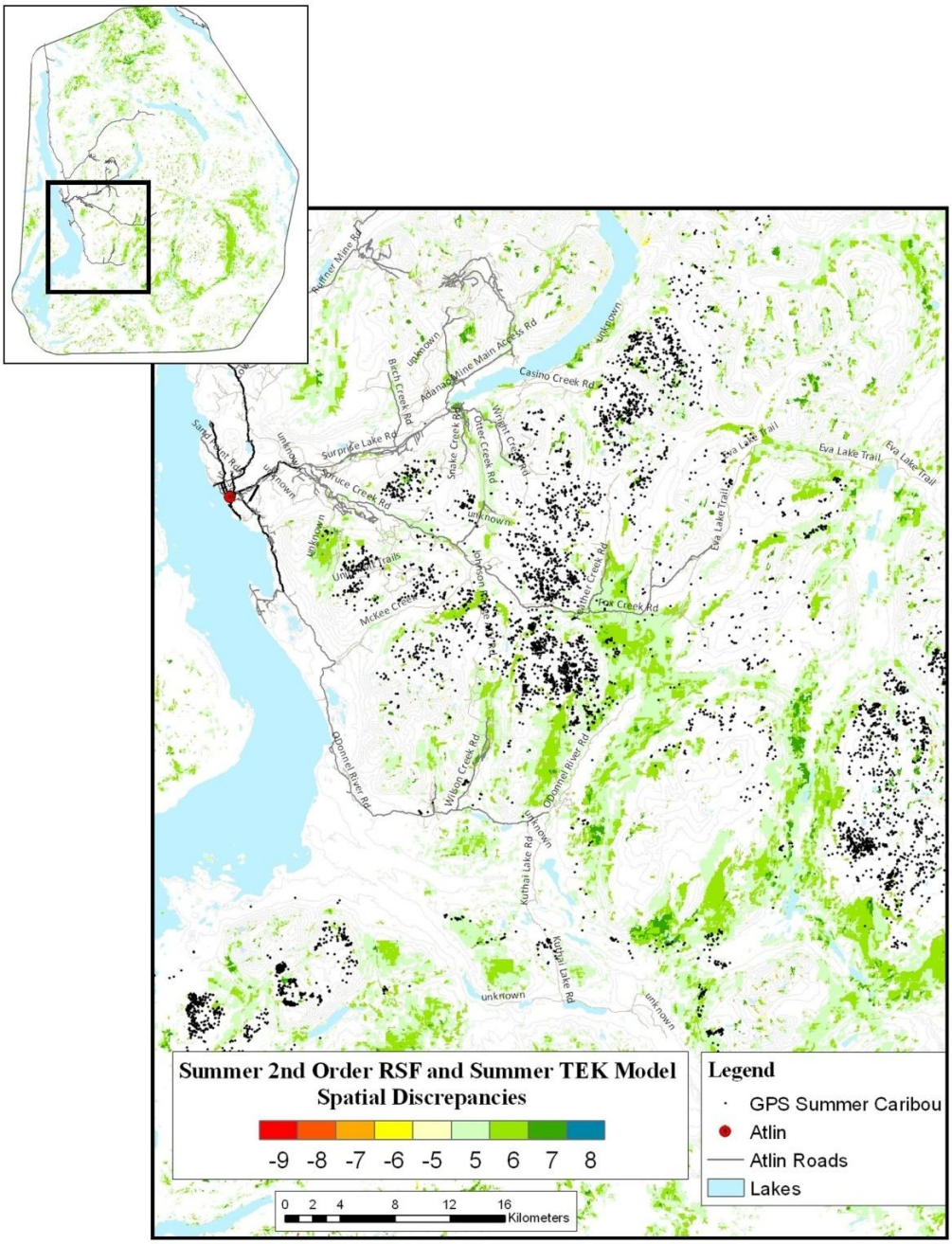


Figure 3-5. Spatial discrepancies between summer realized resource selection function (RSF) generated with spatial information from caribou locations and winter habitat suitability index model generated with the traditional ecological (TEK) knowledge of the Taku River Tlingit First Nation in northern British Columbia, Canada. Warm colors indicate areas where the TEK model predicted high caribou use and the RSF model predicted a low probability of caribou use. Cool colors indicate places where the RSF predicted a high probability of use and the TEK model predicted low caribou use. The numbers represent the difference in habitat classes. For example a positive 8 indicates that the RSF predicted a 10 or 9 and the TEK model predicted a 1 or 2. Only discrepancies of greater than 5 habitat ranks were colored.

CHAPTER 4: REMOTE SENSING-BASED LANDCOVER CLASSIFICATION TO SUPPORT NORTHERN WOODLAND CARIBOU CONSERVATION

INTRODUCTION

The distribution of woodland caribou (*Rangifer tarandus caribou*) in Canada encompasses an extremely diverse range of ecological conditions and human development levels. Recent extinctions of several southern mountain caribou herds (Wittmer et al. 2005a, Hebblewhite et al. 2010) and the decline of many boreal caribou populations (Environment Canada Science Advisory Group 2009) have sparked concern for proactive habitat-conservation measures. The northern mountain ecotype of woodland caribou occurs in local populations throughout the Yukon, Northwest Territories (NWT) and northwestern British Columbia (BC) where ecosystems are less affected by human development. However, even in remote regions, population declines caused by human overharvest, habitat loss and fragmentation from forestry and energy development, human-induced changes to predator-prey communities, and proliferation of road and snowmobile networks prompted federal managers to list northern mountain woodland caribou as a *species of special concern* under the Species at Risk Act (SARA) in 2004 (Kinley and Apps 2001, Thomas and Gray 2002, Seip et al. 2007). Currently, a management plan for the northern mountain population is being developed to identify conservation and land use actions required to ensure that the northern mountain ecotype does not become threatened or endangered.

The range of northern mountain caribou includes the traditional territory boundaries of 33 First Nations across northern Canada (COSEWIC 2002, Northern Mountain Caribou Management Planning Team 2009). The importance of caribou in culture and natural resource use by aboriginal people makes First Nation involvement an important consideration in caribou recovery planning (Manseau et al. 2005, Houde 2007). Federal and provincial guidelines require that management and recovery plans take into consideration co-management agreements between First Nations and provincial governments which can be complicated by unresolved land claims where treaties were never established. Furthermore, because of the remote nature of much of the range of

northern mountain caribou and complex jurisdictional and political issues, there have been few efforts to standardize information on forest inventory or landcover classifications over large areas; an important step in developing wildlife recovery plans (Johnson et al. 2003, McDermid et al. 2009b).

In northwestern BC, current monitoring indicates that the Atlin northern mountain woodland caribou herd has maintained a stable or decreasing population in recent years (Heinemeyer 2006, Taku River Tlingit First Nation and British Columbia 2010). Potential population declines are thought to be due to a combination of historic overhunting, increased human access, and mineral exploration and development (Taku River Tlingit First Nation and British Columbia 2010). This herd occurs within the traditional territory of the Taku River Tlingit First Nation (TRTFN). The TRTFN have a long history of sustainable governance and stewardship of their traditional territory, and value the Atlin caribou herd as a culturally important source of meat and other animal products (Taku River Tlingit First Nation 2003). In the spring of 2007, the TRTFN and the government of BC agreed to enter into joint land-use planning and wildlife management planning in the Atlin/Taku region (TRTFN/BC 2008). One of the key focal species for this joint wildlife management planning was woodland caribou. Because of the high mineral potential in this region, large mine developments within the herd's range are possible in the future. Information concerning landcover requirements of woodland caribou is therefore essential for land use planning as well as caribou management planning initiatives.

Unfortunately, inaccuracies and inconsistencies in the available spatial data on forest types and other landcover characteristics have hindered efforts to model important caribou habitat. Within the TRTFN's traditional territory, a lack of merchantable timber has resulted in low-quality forest inventory, and these data layers provide a poor foundation for caribou research and conservation planning. Spatial data developed from fragmented aerial photography is normally focused on commercially significant forest types, and often overlooks landcover categories that are highly relevant to caribou ecology. Regrettably, the problem is common across much of the species' range, and researchers are often forced to seek alternative information sources. Medium-resolution satellite sensors such as those on board the Landsat, SPOT, and IRS platforms provide an

important supply of vegetation and landcover information with several key advantages over traditional sources (McDermid et al. 2009a). As a result, the use of the technology has increased rapidly, to the point where it now occupies a central role in a growing number of wildlife studies (McDermid et al. 2005, McDermid et al. 2009b). For example, a mounting number of researchers have reported on the use of satellite-derived landcover maps to document important caribou-habitat relationships at large scales across Canada (e.g., Poole et al. 2000, Edenius et al. 2003, Johnson et al. 2003, Bechtel et al. 2004, Ferguson and Elkie 2005, Tamstorf et al. 2005, Gustine and Parker 2008). However, detailed descriptions of the *methods* required to process satellite data reliably over large, diverse study areas are largely absent from the wildlife literature. As a result, the goal of our research was to develop a strategy for performing remote sensing-based landcover classification in a manner capable of supporting detailed caribou habitat conservation planning. While the work is centered on the traditional territory of the TRTFN, we believe that the approach is robust enough to be applied across caribou range elsewhere, and in this manner represents an important set of methods for extracting landcover classes that are relevant to caribou research and conservation. The value of the new product is demonstrated by an application that estimates the relative selection of landcover types by the Atlin herd using logistic regression.

METHODS

FIELD DATA

While remote sensing-based classification strategies can follow supervised, unsupervised, or hybrid approaches, the *supervised* strategy – wherein the analyst guides the categorization of pixels through the use of a-priori knowledge, field plots, or other information – is often the best strategy for arriving at specifically defined information classes (McDermid et al. 2009b). In order to accomplish this, we used series of vegetation inventory sites that were visited in the field between 2003 and 2008. Information recorded at these sites included landcover type and detailed species composition in each layer of the vegetation structure, which was used to define the landcover information classes that comprise the response variable (Table 4-1). The selection of these sites followed a stratified random sampling design, whereby at least 15

sites per landcover category and accessibility were considered. We recorded spatial location using Garmin GPS Map60 handheld units. A total of 617 forested sites were visited directly and supplemented by 356 locations from a similar inventory of alpine environments and 151 additional locations collected from Landsat TM imagery for broad, non-vegetated classes.

REMOTE SENSING DATA ACQUISITION AND PRE-PROCESSING

A study area-wide set of geospatial predictor variables was assembled to generate the final classification product (Table 4-2). We obtained two Landsat TM images from (path/row) 57/18 and 57/19, both acquired on July 26, 2006 and September 15, 2006, respectively, from the USGS Landsat archive. These images were acquired with a systematic correction (Level 1G), whereby the scenes are radiometrically and geometrically corrected to accuracies of roughly 100 m. Supplemental ortho-rectification of the imagery to finer spatial tolerances was performed using Orthoengine software from PCI (Richmond Hill, Ontario). We collected a series of ground control points from existing geographic information system (GIS) road layers and extracted elevation values from a Canadian Digital Elevation Data digital elevation model (DEM) downloaded from Geobase. The root-mean-square error of the final orthorectificatied imagery was 0.25 Landsat TM pixels, or 7.5 m.

The ortho-rectified Landsat TM imagery was used to derive *brightness*, *greenness* and *wetness* variables information from tasseled-cap transformation of Crist and Cicone (1984), following a conversion to top-of-atmosphere reflectance using the methods outlined by Chander and Markham (2003). Wetness difference was calculated from wetness information for each acquisition date of the Landsat TM imagery. The normalized *difference vegetation index* (NDVI) was also calculated for each acquisition date, according to:

$$NDVI = \frac{Band4 - Band3}{Band4 + Band3}$$

where $Band4$ is the near infrared (NIR) band and $Band3$ is the red band of Landsat TM imagery and NDVI difference was calculated in the same manner as wetness difference.

While landcover can be classified successfully on the basis of spectral variables alone, previous studies have demonstrated the improved performance of data sets enhanced with topographic explanatory variables, particularly in areas of pronounced topography (Franklin 1994). In order to accomplish this, *slope* and *aspect* were both calculated using the spatial analyst extension in ArcGIS (Redlands, California). The compound topographic index (CTI) of Moore et al. (1993) is well-known surrogate of soil attributes, derived with the formula:

$$CTI = \ln\left(\frac{A_s}{\tan\beta}\right)$$

Where A_s is the catchment area expressed as m^2 per unit width orthogonal to the flow direction, and β is the slope angle express in radians (Gessler et al. 1995).

CLASSIFICATION APPROACH

A classification-tree approach for determining landcover was performed using See5 data mining software (Rulequest Research, St. Ives Australia). Classification trees are non-parametric algorithms used to predict class membership of cases of a categorical response variable from the measurements of one or more predictor variables (Friedl and Brodley 1997), and have been shown to be broadly applicable for classifying land cover under a wide variety of conditions (e.g., Lees and Ritman 1991, Lawrence et al. 2004, Lu and Weng 2007). In this analysis, a training dataset consisting of 1124 locations, each with one of 14 observed landcover classes and values from each geospatial prediction layers was processed to create a set of decision rules defining the occurrence of each class on the landscape. Along with a rule set, confidence values for each rule were obtained, according to the Laplace ratio:

$$confidence = \frac{n - m + 1}{n + 2}$$

where n is the number of training cases covered by the rule, and m is how many of those training cases do not belong to the class predicted by the rule. It is common place that several rules may be applicable, and when it happens that one or more rules predict

different classes, an implicit conflict results. This conflict can be resolved be either taking the class with the highest confidence value, or by aggregating the confidence values for all rules of a particular class. We chose the latter method of conflict resolution between rules and utilized custom code to transfer decision rules using this method to raster output in IDL (ITT, Boulder, Colorado). The output raster was then filtered using an object-oriented majority filtering technique whereby image segmentation was run on the original Landsat TM data using Definiens Professional (Munchen, Germany) to produce image objects, and the majority class of the pixels beneath each object was assigned.

Validation of the final land cover model was performed using a *k*-fold cross validation, with a *k* value of 10. *K*-fold cross validation has been used for accuracy assessment in remote sensing applications (e.g., Friedl et al. 2000, Zimmermann et al. 2007). A confusion matrix was constructed from the combined results of the *k*-fold cross validation trials and accompanying user's, producer's and overall accuracies were calculated. In addition, a KHAT statistic was calculated as a measure of agreement between the observed and predicted classes for the *k*-fold cross validation confusion matrix:

$$\hat{k} = \frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r}(x_{i+} \bullet x_{ii})}{N^2 - \sum_{i=1}^{r}(x_{i+} \bullet x_{+i})}$$

where r is the number of rows in the error matrix; x_{ii} is the number of observations in row i and column i (on the major diagonal); x_{i+} is the total observations in row i (shown as marginal to right of the matrix); x_{+i} is the total of observations in column i (shown as marginal total at the bottom of the matrix); and N is the total number of observations included in the matrix.

ANIMAL CAPTURE

Eight female and 2 male caribou were radio-collared and monitored with GPS telemetry collars (GPS 2000, LOTEK, Aurora, ON) between December 1999 and January 2002 by the Ministry of Water, Land, and Air Protection of British Columbia (Diemert 2001). Caribou were captured by helicopter net-gunning according to Wildlife Radio-Telemetry, Standards for Components of BC's Biodiversity No. 5, RIC 1998. Global

positioning system collars were scheduled to attempt a location every 4 hours. A total of 16,270 GPS locations were collected. Because GPS fix success was > 90% we did not need to correct for habitat induced bias (Frair et al. 2004).

CARIBOU SELECTION

To assess caribou landcover associations during the winter we examined the relative use of landcover types at the second-order or landscape scale (Johnson 1980). We evaluated selection during winter (15 Nov – 15 May) because caribou population declines have been linked to the quality of winter habitat (Wittmer et al. 2005c). We employed a use-availability design described by Manly et al. (2002) by comparing resource covariates at used locations to random available locations within the fixed kernel estimator home range of the Atlin herd. Availability was estimated with 1:1 random locations using Hawth's Tools Extension v. 3.27 (Beyer 2004) within ArcGIS 9.3.1. We evaluated landcover associations using the fixed-effect exponential form of the logistic model given as:

$$w^*(x) = \beta_0 + \beta_1 x_1 + \ldots + \beta_n x_n + \epsilon$$

where $w^*(x)$ is proportional to the predicted probability of use as a function of covariates $x_{1\ldots n}$, and $\beta_{1\ldots n}$ are the beta coefficients estimated from logistic regression (Manly et al. 2002).

We included resource covariates of elevation (m) and slope extracted from the TRIM digital elevation model (DEM) using Spatial Analyst for ArcGIS 9.3.1. Because no used locations occurred in snow, the category was dropped from the model. We combined Mountain Aven and Heather to form a new class designated as alpine tundra. In total, 12 cover types were defined with mixed conifer and mixedwood representing the reference category. Logistic regression was estimated using STATA 10.1 (StataCorp Lp, TX). Beta coefficients (selectivity) for each landcover category were based on the reference for comparison (Long and Freese 2000, Boyce et al. 2002a). To determine the importance of each variable we used manual stepwise entry to select models and then compared a small subset of models using Akaike's information criterion (ΔAIC) to select

a top model (Manly et al. 2002). Model fit was evaluated using k-folds cross validation (Boyce et al. 2002b) to determine overall model predictability.

RESULTS AND DISCUSSION

Figure 4-1 displays the output landcover classification model from the classification-tree approach. A qualitative assessment of the map product reveals a spatial consistency that is suitable for this type of output. Table 3 displays the summary of the *k*-fold cross validation trials on the model land cover prediction. The mean error from the analysis was 24.59 % with a standard error of 1% (Table 4-3). A low error of 19.8% occurred at fold nine and a high error of 30.4% occurred at fold 10 (Table 4-3). The mean number of rules from the k-fold cross validation was 72, with a standard error of 1.6 (Table 4-3). The largest number of rules recorded was 78, occurring at fold 4 and fold 10, while the smallest number of rules recorded was 61, occurring at fold 6 (Table 4-3). Table 4 displays the error matrix resulting from *k*-fold cross validation of model prediction. The overall accuracy of the land cover classification model was 75%, with producer's accuracies ranging from a low of 41% for the mixedwood class to a high of 100% for the snow and ice class (Table 4-4). User's accuracies range from a low of 24% for the fescue class to a high of 100% for water class (Table 4-4). The KHAT statistic for this error matrix is 0.73, indicating that it is 73% better than one resulting from chance. At the second-order scale during winter, caribou selected for lodgepole pine/lichen complexes, spruce/fir forests, and low valley open areas comprised predominately of salix species (Table 4-5). Overall caribou selected for mid elevations of approximately 1000 m and moderate slopes. Mixed conifer was the most prevalent landcover types within the home range of the Atlin herd and caribou used this forest type in proportion to availability. Mixedwood was also subsumed into the intercept because use was not significantly different than availability. Caribou strongly avoided deciduous stands of aspen, which were relatively rare on the landscape. Alpine habitats of fescue, alpine tundra and krummholz were also avoided. Caribou did not select for alpine shrub, but did not avoid it as strongly as other alpine habitats. Exposed rock was also avoided and very rare within the home range of the Atlin herd. Only 2 caribou had used locations that intersected rock. In winter caribou also avoided frozen lakes (Figure 4-2), though this could be a result of lake size and availability. In general, the predictive performance of

the model was good indicated by the pseudo r^2 (0.123) and k-folds cross validation (average Spearman-rank: 0.968).

Table 4-1. Landcover types classified with Landsat TM satellite imagery territory of the Taku River Tlingit First Nation of northern British Columbia.

	Cover Type	Description
1	LP/Lichen	Level areas with well-drained soils that support stands of lodgepole pine (*Pinus contorta var. latifolia*) and an understory of *Cladina* and *Cladonia* species.
2	Spruce/Fir	Forest dominated by white spruce (*Picea glauca*) and sub-alpine fir (*Abies lasiocarpa*) with minor components of lodgepole pine (*Pinus contorta var. latifolia*).
3	Mixed Conifer	Older Stands that comprise variable composition of white ppruce (*Picea glauca*), sub-alpine fir (*Abies lasiocarpa*), and lodgepole pine (*Pinus contorta var. latifolia*).
4	Aspen	Over-grown, high shrub, or closed stands of trembling aspen (*Populus tremuloides*) that may contain black cottonwood (*Populus balsamifera spp. trichocarpa*).
5	Mixedwood	Medium-aged stands that comprise variable composition of white spruce (*Picea glauca*), sub-alpine fir (*Abies lasiocarpa*), lodgepole pine (*Pinus contorta*), trembling aspen (*Populus tremuloides*) and black cottonwood (*Populus balsamifera spp. trichocarpa*).
6	Fescue	Thick grassy areas in high elevation environments that contain *Festuca* species.
7	Krummholz	Windswept landscape near tree-line characterized by stunted vegetation in a variety of species including, white spruce (*Picea glauca*) and sub-alpine fir (*Abies lasiocarpa*).
8	Mountain Aven	Dwarf, trailing, or mat forming shrubs characterized by *Dryas* species.
9	Mountain Heather	Moist slopes not far above tree line characterized by *Cassiope mertensiana*.
10	Low Valley Salix	Shrub, sedge, and forb dominated lowlands with high water table usually dominated by *Salix* species.
11	Alpine Shrub	Alpine environments dominated by low-height plant species such as scrub birch (*Betula glandulosa*) and *Salix* species
12	Rock/Talus	Rocky terrain with very sparse vegetation. Can include lichen cover of *Umbilicaria*, *Cetraria* and *Cladina* species.
13	Snow/Ice	High elevation areas above the tree-line or otherwise dominated by glaciers and heavy snow.
14	Water	Area of low slope and depression where water aggregates and the water table is above grade.

Table 4-2. Geospatial layers used for prediction variables in landcover model in the territory of the Taku River Tlingit First Nation of northern British Columbia.

Geospatial layer	Description
NDVI	Normalized Difference Vegetation Index (NDVI) is calculated from the ratio of red and near infrared (NIR) and is used to determine the amount of healthy vegetation present.
NDVI difference	NDVI difference is the result of subtracting two NDVI values from different times of the year. If the difference between NDVI values from leaf-on and leaf-off or senescent deciduous trees can be obtained, it can aid in discriminating between tree species.
BGW	Brightness, greenness and wetness (BGW) is calculated from the Tasseled-cap transformation of Landsat data and is used to differentiate between landcover types, since values differ greatly with surface cover.
Wetness Difference	Wetness difference is determined by subtracting two wetness values from different times and can be used to identify areas of change.
Elevation	Elevation is obtained from a digital elevation model (DEM) and can be used to differentiate between species if they exhibit elevation-dependent distributions.
Slope	Slope is calculated from a DEM by calculating the rise-over-run of two points and can be used to differentiate between species if they exhibit slope-dependent distributions.
Aspect	Aspect is calculated from a DEM by calculating down-slope direction of the maximum rate of change in value from each cell to its neighbors and can be used to differentiate between species if they exhibit aspect-dependent distributions.
CTI	Compound Topographic Index (CTI) is a steady-state wetness index and it is a function of both the slope and the upstream contributing area per unit width orthogonal to the flow direction. It can be used to give an indication of horizon depth, silt percentage, organic matter and phosphorous content, which is useful if particular landcover is related to these attributes.

Table 4-3. Summary of *k*-fold cross validation trials on model prediction for the landcover model in the territory of the Taku River Tlingit First Nation of northern British Columbia.

Fold	No. of Rules	Errors (%)
1	68	23.6
2	73	27.1
3	72	26.3
4	78	25.4
5	70	25.4
6	61	24.5
7	75	22.7
8	74	20.7
9	71	30.4
10	78	19.8
Mean	72.0	24.59
SE	1.6	1.0

Table 4-4. Error matrix resulting from *k*-fold cross validation of model prediction for the landcover model in the territory of the Taku River Tlingit First Nation of northern British Columbia.

	Validation Data (Known Land Cover Types) [a]														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**Total**
Classified Data															
1	30	7	8		3		1			2	3				54
2	4	32	9	1	3		1			1	2				53
3	6	12	69	2	6						3				98
4		3	2	44	7					2	1				59
5	2	6	10	7	17					2				1	45
6						11	5	5	11		6	8			46
7		1	1	6			69		1		6	1			85
8						5		86	4		2	9			106
9	1					3	1	7	106		5	6			129
10	5	3		4	3					7	3				25
11	1	1	3		2	2	7	2	5		115				138
12						2		8	9		3	86			108
13								1		1		2	105		109
14														69	69
Total	49	65	102	64	41	23	84	109	136	15	149	112	105	70	1124

Producer's Accuracy		**User's Accuracy**	
1 = 61%	8 = 79%	1 = 56%	8 = 81%
2 = 49%	9 = 78%	2 = 60%	9 = 82%
3 = 68%	10 = 47%	3 = 70%	10 = 28%
4 = 69%	11 = 77%	4 = 75%	11 = 83%
5 = 41%	12 = 77%	5 = 38%	12 = 80%
6 = 48%	13 = 100%	6 = 24%	13 = 96%
7 = 82%	14 = 99%	7 = 81%	14 = 100%

Overall Accuracy = 75%
Kappa Coeff. = 0.73

[a]1, LP/Lichen; 2, Spruce; 3, Mixed Conifer; 4, Aspen; 5, Mixedwood; 6, Fescue; 7, Krumholz; 8, Mountain Aven; 9, Mountain Heather; 10, Wetland\Wet Seepage; 11, Shrub; 12, Rock\Talus; 13, Snow and Ice; 14, Water.

Table 4-5. Coefficients of landcover selection by northern mountain woodland caribou during winter (15 Nov – 15 May). Selection was estimated by comparing resource covariates at used locations to random available locations within the home range of 10 GPS collared caribou near Atlin, BC. Locations were collected between 1999 and 2003 by the Ministry of Water, Land, and Air Protection of Canada.

Covariate	**Coefficient**	**SE**	**p**
Slope	-0.0348392	0.00329	< 0.0005
Elevation	0.0147288	0.001085	< 0.0005
Elevation^2	-6.70E-06	5.13E-07	< 0.0005
LP/Lichen	0.6089385	0.057995	< 0.0005
Spruce/Fir	0.4302928	0.059941	< 0.0005
Aspen	-1.18009	0.306252	< 0.0005
Fescue	-1.080651	0.38199	0.0050
Krummholz	-0.9988247	0.141563	< 0.0005
Low Valley Salix	0.7024014	0.08294	< 0.0005
Alpine Shrub	-0.2071567	0.062513	0.0010
Rock	-1.997278	0.607308	0.0010
Water	-1.414771	0.12821	< 0.0005
Alpine Tundra	-1.04019	0.168892	< 0.0005
Intercept	-7.533273	0.570062	< 0.0005

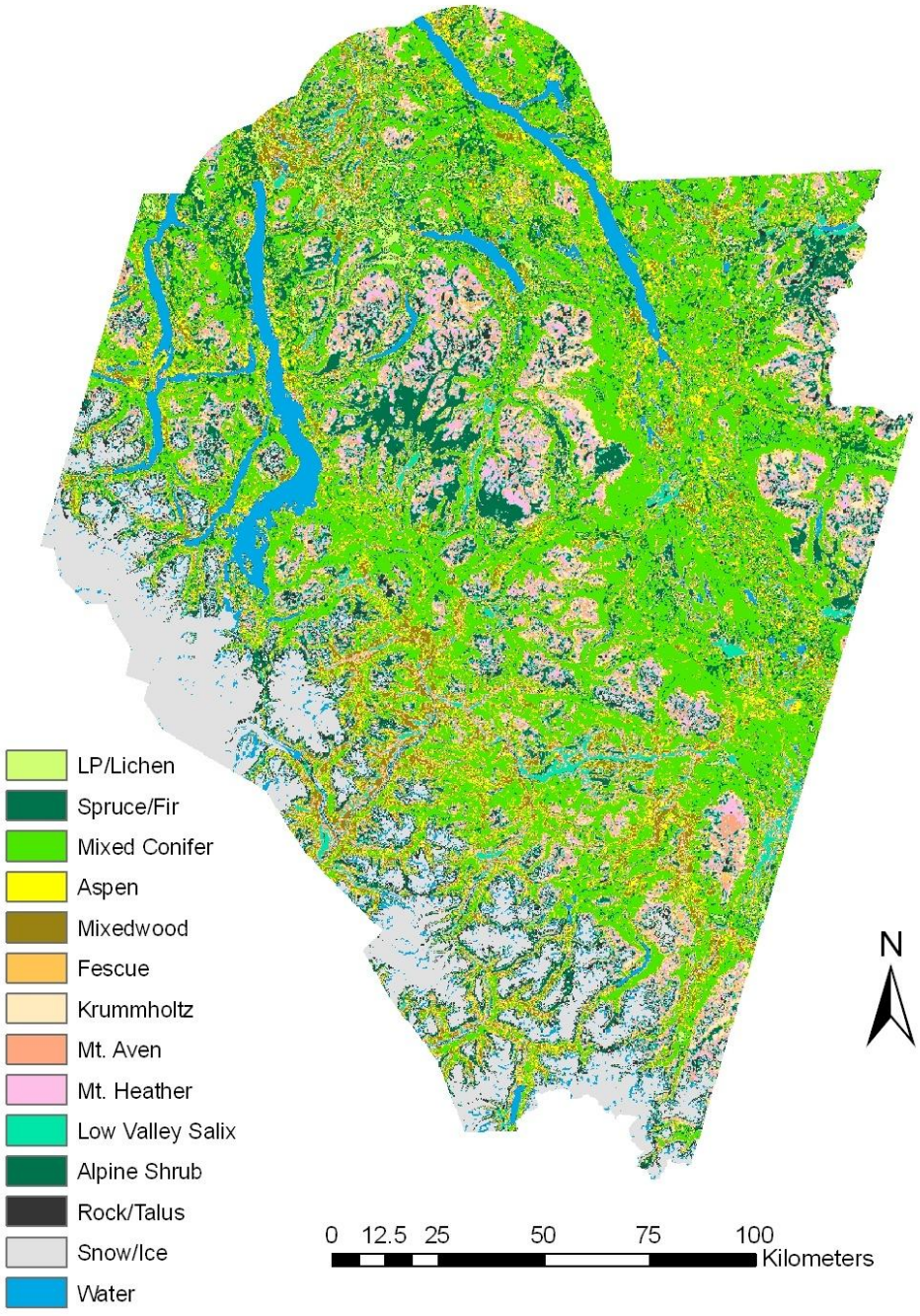


Figure 4-1. Landcover classification for the landcover model in the territory of the Taku River Tlingit First Nation of northern British Columbia.

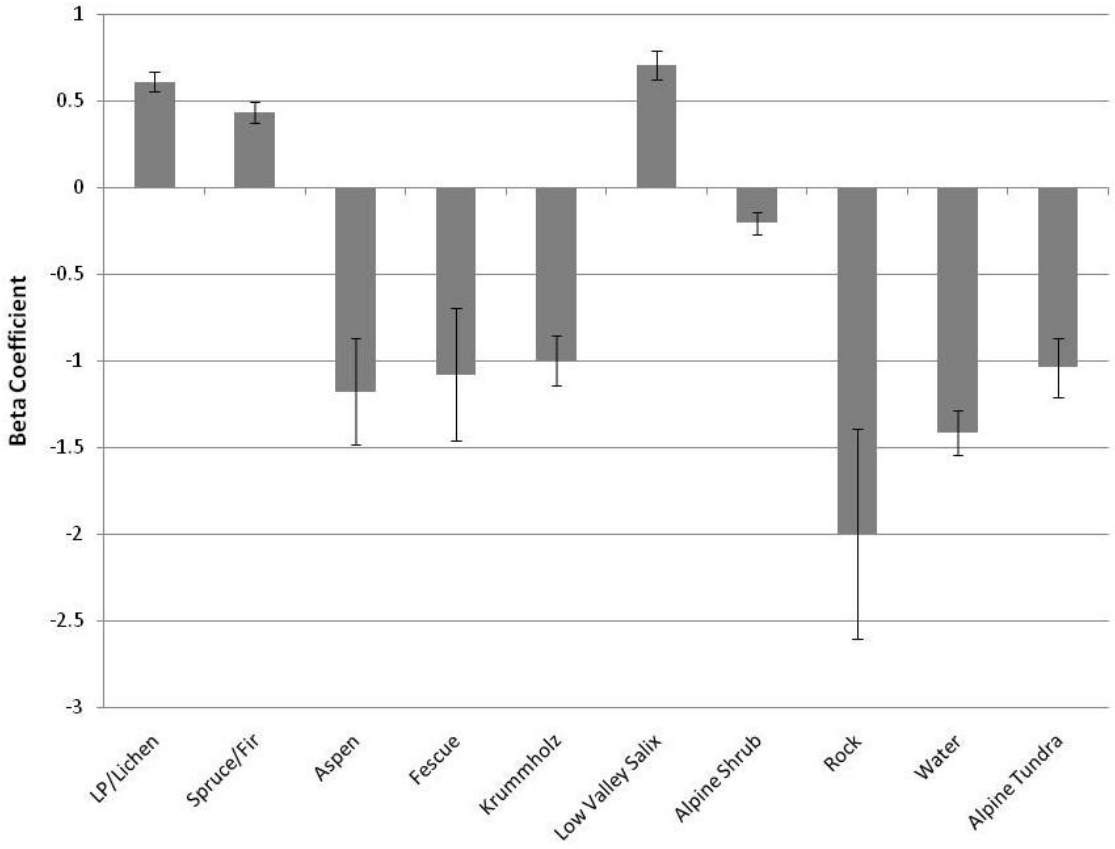


Figure 4-2. Selection of landcover types by 10 GPS collared northern mountain woodland caribou during winter (15 Nov – 15 May) near Atlin, BC. If coefficient is positive it indicates selection (the number of used locations was greater than random available locations) and if the coefficient is negative it indicates avoidance. Locations were collected between 1999 and 2003 by the Ministry of Water, Land, and Air Protection of Canada.

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APPENDIX A: ADDITIONAL INFORMATION

Table A-1. Estimates of caribou selectivity (β) coefficients and standard errors (SE) from realized and potential generalized linear mixed models with a random intercept at the second-order scale for the Atlin herd of northern mountain woodland caribou in northern British Columbia. Selection was measured in summer (May16-Nov14) from 2000-2002. The realized model includes the human zone of influence (ZOI) covariate, while potential model does not. Positive selectivity coefficients indicate selection for that covariate and negative selectivity coefficients indicate avoidance. Squared terms (such as slope^2) indicate that the relationship was quadratic (i.e., caribou selected for intermediate slopes). Selection for high values of hillshade represent selection for western slopes with high sun exposure.

Summer second-order	Realized		Potential	
Covariate	**Selectivity β**	**SE**	**Selectivity β**	**SE**
LP/lichen	-0.7327	0.1465	-0.7336	0.1455
Mixed Con	-0.8568	0.0920	-0.8438	0.0891
Krummholz	0.3286	0.1131	0.3285	0.1083
Alpine Shrub	0.4950	0.1031	0.4755	0.0955
Alpine Tundra	0.5956	0.1117	0.5854	0.1089
Rock	0.2981	0.1388	0.3077	0.1376
Water	-3.1979	0.3123	-3.2067	0.3113
Elevation	0.0121	0.0012	0.0120	8.37E-04
Elevation^2	-4.44E-06	4.54E-07	-4.39E-06	3.29E-07
Slope	0.0374	0.0078	0.0351	0.0078
Slope^2	-0.0023	2.27E-04	-0.0022	2.26E-04
Hillshade	0.0036	5.82E-04	0.0038	5.75E-04
NDVI summer	-2.71E-04	1.66E-05	-2.71E-04	1.51E-05
Percent Snow winter	8.2122	0.3753	8.4300	0.3651
Human ZOI summer	-0.4785	0.0608		
Constant	-14.9905	0.6986	-15.2352	0.5526

Notes: Abbreviations are LP, lodgepole pine; NDVI, Normalized Difference Vegetation Index; ZOI, cumulative human Zone of Influence.

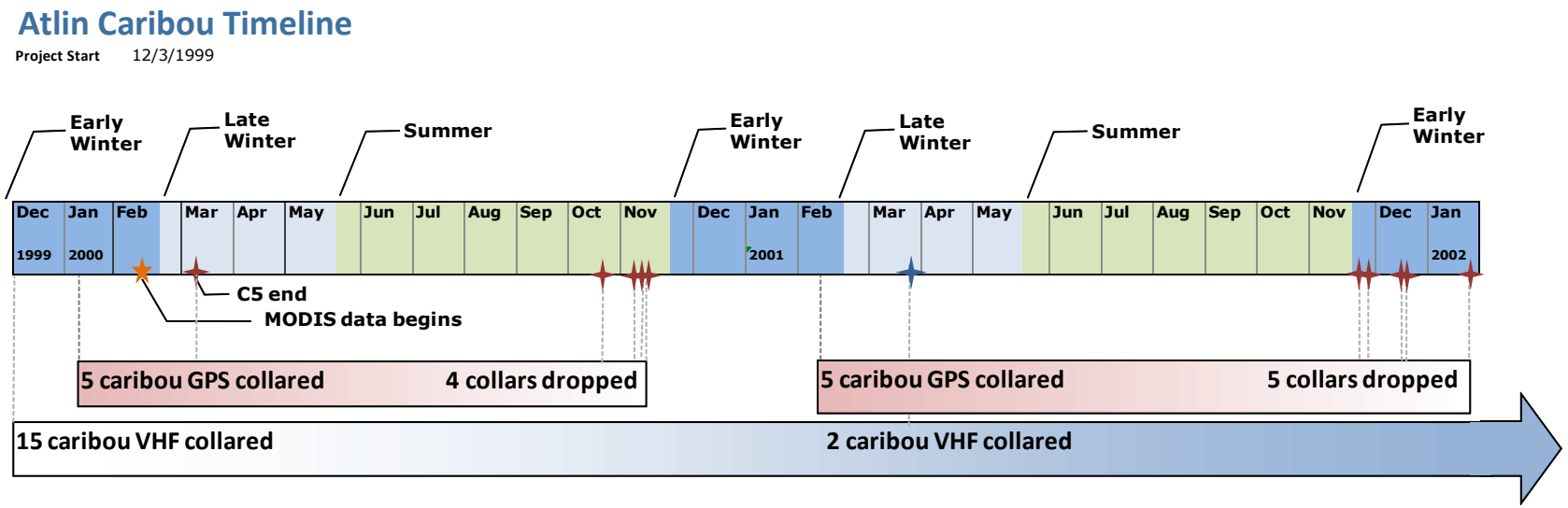
Table A-2. Estimates of caribou selectivity (β) coefficients and standard errors (SE) from realized and potential generalized linear mixed models with a random intercept at the second-order scale for the Atlin herd of northern mountain woodland caribou in northern British Columbia. Selection was measured in winter (Nov15-May15) from 2000-2002. The realized model includes the human zone of influence (ZOI) covariate, while potential model does not. Positive selectivity coefficients indicate selection for that covariate and negative selectivity coefficients indicate avoidance. Squared terms (such as slope^2) indicate that the relationship was quadratic (i.e., caribou selected for intermediate slopes). Selection for high values of hillshade represent selection for western slopes with high sun exposure. Percent snow cover coefficients were square transformed.

Winter second-order	Realized		Potential	
Covariate	**Selectivity β**	**SE**	**Selectivity β**	**SE**
LP/lichen	0.569	0.0624	0.594	0.0620
Krummholz	-0.919	0.1399	-0.897	0.1394
Burn LP	-0.866	0.1684	-0.795	0.1678
Spruce/fir	0.232	0.0625	0.264	0.0618
Low Valley Salix	0.687	0.0937	0.724	0.0929
Alpine Tundra	-0.699	0.1634	-0.642	0.1628
Rock	-1.659	0.6140	-1.621	0.6154
Water	-0.827	0.1519	-0.781	0.1500
Elevation	0.017	0.0012	0.019	0.0012
Elevation^2	-7.23E-06	5.640E-07	-7.82E-06	5.620E-07
Slope	-0.050	0.0034	-0.051	0.0033
Hillshade	0.006	0.0009	0.006	0.0009
NDVI summer	0.003	0.0003	0.003	0.0003
NDVI summer^2	-2.83E-07	2.310E-08	-2.79E-07	2.300E-08
Percent Snow winter	9.552	0.6575	9.607	0.6502
Percent Snow winter^2	-7.655	0.4531	-7.663	0.4486
Human ZOI winter	-0.954	0.0739		
Constant	-22.795	1.1244	-23.652	1.1176

Notes: Abbreviations are LP, lodgepole pine; NDVI, Normalized Difference Vegetation Index; ZOI, cumulative human Zone of Influence.

Table A-3. Average summer Normalized Difference Vegetation Index (NDVI) across specific landcover types for 2000 and 2001 within the winter and summer kernel home ranges of the Atlin herd of northern mountain woodland caribou in northern British Columbia. NDVI was measured at a 250 m^2 resolution from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) satellites.

Landcover Type	Average NDVI
Snow/Ice	0.2091
Water	0.2860
Rock/Talus	0.3734
Alpine Tundra	0.4367
Alpine Shrub	0.6128
Low Valley Salix	0.6142
Krummholz	0.6176
Spruce/Fir	0.6657
Mixedwood	0.6746
LP/Lichen	0.6757
Burned LP	0.6824
Aspen	0.6984
Mixed Conifer	0.7120



Notes: Abbreviations are MODIS, NASA's Moderate Resolution Imaging Spectroradiometern satellite data; C5, refers to caribou ID (see Table 2-1).

Figure A-1. Timeline of northern mountain woodland caribou location data collected between December 1999 and March 2003 by the Ministry of Water, Land, and Air Protection of Canada to address potential impacts of the proposed Tulsequah mine and access road in northern British Columbia, Canada. Five global positioning system (GPS) collars were deployed on 10 January 2000 and scheduled to self-release in November 2000. The five GPS collars were retrieved, refurbished and re-deployed on 13 February 2001. Details on end dates for the 17 very high frequency (VHF) collared animals can be found in Table 2-1.

APPENDIX B: TRADITIONAL ECOLOGICAL KNOWLEDGE COLLECTION

TAKU RIVER TLINGIT FIRST NATION – ECOLOGICAL KNOWLEDGE INTERVIEW QUESTIONS

This question set was a first developed in a joint project by the Taku River Tlingit First Nation (TRTFN) and Round River Conservation Studies to document TRTFN Traditional Ecological Knowledge regarding wildlife in Taku River Tlingit First Nation Traditional Territory.

The information that you choose to share in this interview will be used to produce a report that documents this knowledge. The specific information that you choose to share will be documented in a map showing your ecological memory and knowledge. Collectively the individual maps will then be used to produce an aggregate map overlay that will serve to identify biologically important and sensitive areas for the Taku's wildlife, based upon your collective expert knowledge. When combined with maps of documenting wildlife information developed by the provincial and federal governments, and the wildlife field research being carried out by the TRTFN Land and Resources Office and Round River. The two sets of knowledge will be used in a wildlife conservation areas design to describe potential protective area strategies for preserving the ecological integrity of TRT traditional territory.

You will be given a copy of the map produced from the knowledge that you have shared, a copy of the aggregate map, and report that is produced from collective shared knowledge and a copy of the report and maps that are part of the conservation areas design.

Date:
Name: Number of years Hunting/Trapping/Gathering:
Age: Mailing Address:
Gender:
Clan:
House: Interviewer(s):

Introduction

1. What is the Tlingit name for this animal?
2. Are there any Tlingit names for different types of this animal?
3. How big does this animal get in size and weight?
4. Do males look different from females?
5. Does the way this animal looks change from season to season?
6. Does this animal make any sounds?
7. Does this animal have any special marks?
8. When you want to know if this animal lives in the area, what signs do you look for?

Animal's Life

9. Does this animal live alone?
10. What does this animal do at different times of the year?
11. What does this animal so during the day or night?
12. What is the most interesting thing you have learned about this animal?
13. Do you ever see this animal do something unusual?
14. Do you think this animal is smart?
15. What time of the year and how do males and females start looking for each other to have young ones?
16. How old is the animal when it has young ones for the first time?
17. How often do females have young ones? Several times a year, each year, once in several years?
18. In what places do the females give birth to their young ones? (identify on map)
19. How many young ones do they usually have?
20. How do the young ones learn to feed on their own?
21. Is there anything that the parents teach their young ones?
22. How do they protect the young ones from danger?
23. How long do the young ones stay with their parents?
24. In what kind of places or habitats does this animal like to live in the winter? In the spring? In the summer? In the fall?
25. Are there specific places where this animal is most likely to be found? (Identify on map)
26. Does this animal build anything for itself?
27. What food does this animal eat?
28. What does this animal do when there is a fire in the area?
29. Have you ever found this animal sick or dead?
30. Do the numbers of this animal change from year to year? Do you know why this happens?
31. Do you find this animal in different places at different times of the year? (identify on map) Do you know why this happens?
32. Do other animals hunt this animal? Can you describe how they do it?
33. How does this animal escape danger and defend itself?

Utilization

34. Why is this animal important to the Tlingit?
35. Is it as important to the Tlingit today as it was long ago?
36. What time of the year do you hunt this animal?
37. How do you prepare yourself to go hunting or trapping this animal? Do you know how it was done long ago?
38. Do you know any Tlingit rules about what to do BEFORE hunting or trapping this animal?
39. Do you know any Tlingit rules about where you can hunt or trap this animal?
40. Do you know any Tlingit rules about how many animals you can kill during one hunt or during a whole season?
41. Can you describe some ways of hunting this animal?
42. Have the ways you hunt this animal changed?
43. Do you know of any Tlingit rules about what to do WHEN hunting or trapping this animal?
44. Can you describe some tricks you may have learned to make your hunting or trapping of this animal more successful?
45. What makes a Tlingit a good hunter or trapper of this animal?
46. Can you describe how the Tlingit prepare and store the skin?
47. Do you know how the Tlingit use this animal's skin?
48. Can you describe some ways to cut up this animal's meat and insides?
49. How did the Tlingit store this animal's meat and skin long ago? What about today?
50. Can you describe what people did with this animal's meat and insides long ago?
51. What did the Tlingit do with this animal's bones long ago? What about today?
52. Do you know if Tlingit used some parts of this animal as medicine long ago?
53. How did the Tlingit share different parts of the animal's meat and insides long ago? What about today?
54. Do you know any Tlingit rules about what to do AFTER hunting or trapping this animal?
55. What will happen if the hunter does not follow these rules?
56. Can the Tlingit joke or brag about this animal?
57. Long ago, what would Tlingit do with unused part of this animal after the hunt? What about today?
58. How did the Tlingit show their respect for this animal?
59. What do you think should be done to make sure there are enough of this animal for future generations of Tlingit.
60. Do non-Tlingit hunt or trap this animal? In what places do these other people hunt or trap this animal? (identify on map)

Origin

61. Do you know any old time legends about this animal?
62. Have you heard of stories when this animal would visit people in their dreams?

Conclusion

63. Is there anything else you would like to say about this animal?
64. Is there anything we can do to make this interview better?

Table B-1.Summary of Taku River Tlingit First Nation member's responses to questions regarding northern mountain woodland caribou habitat selection in northern British Columbia.

	Caribou					
Initials	**Spring Food/Habitat**	**Summer Food/Habitat**	**Fall Food/Habitat**	**Winter Food/Habitat**	**General Food/Habitat**	**Notes**
AW	low-elevation forest. food: lichen	mountain tops, high elevation, feed on lichen, use snowfields on north facing slopes to escape flies		low-elevation forest	salt licks	migrate from mountain top to forest
BJ	use last of snow on mountain to escape flies	high elevation on mountain sides and slopes, mountain tops. Food: caribou moss and caribou grass	high elevation on mountain sides and slopes	slopes that are windblown clear of snow, low elevation lakes	open lowlands with low shrubs	migrate from mountain to mountain
DJ	calve at high elevations	mountain tops, thick brush, bigger (in volume) mountains with more grazing, escape flies in snow fields	high elevation on mountains, thick brush	windblown slopes cleared of snow	food: buckbrush buds, caribou moss, dig up grasses, use lakes to avoid predators	Migrate between seasons, move around a lot between areas within a season
GT	move to water with young in May	high elevation in mountains to graze	high in mountains, rut high in mountains	go to lower elevations for food when snow comes, low elevation forest	food: lichens growing on ground/in tundra, caribou leaves, grasses, get minerals by eating gravel and soil	use same migratory routes, escape predators in water
HC	keep young high in mountains, have young on islands for protection	high in mountains, but move around a lot	high in mountains	high in mountains, valleys and forest	food: caribou moss/lichen, mountain grasses, buckbrush, dwarf birch	
RC	calve on mountains	wide-ranging	high in mountains, start migrating north	move down to low-elevation into lodgepole, move down to flats when snow is too deep in mountains	live in country with a lot of caribou moss	
TJ	low-elevation meadows, lakes. food: grass, willow	varies, wander a lot: both above and below treeline, food: grass, willow	way above treeline in mountains, in tundra with lots of caribou moss	lower elevations in river bottoms and valleys with thick vegetation. food: old brush leaves, grass		
JW	calve where protected from wolf high in mountains. food: grass and other vegetation	high rolling mountain terrain. food: grass and other vegetation		come down into lower elevation valleys, in forest. food: dig for caribou moss, only eat moss in winter, dig for caribou leaves	wide-ranging	