TONQUIN CARIBOU RISK ASSESSMENT FINAL REPORT

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EXECUTIVE SUMMARY

The Marmot Basin Ski Area Guidelines for Development and Use requires completion of a caribou risk assessment to support Parks Canada in determining whether to consider new developments in the Tres Hombres and Outer Limits portions of the Marmot Basin Ski Area. The Tonquin caribou population belongs to the Central Mountain Caribou Designatable Unit (COSEWIC 2011), and is presently listed as *Threatened* by the Committee on the Status of Endangered Wildlife (COSEWIC). More recently, the proposed Recovery Strategy for the Woodland Caribou, Southern Mountain Population (*Rangifer tarandus caribou*) in Canada identified the threat level in Central Mountain herds as 'Very High' (Environment Canada 2014). The Marmot Basin Ski Area, established in the 1960's, is located in the northeastern portion of the Tonquin caribou population range and within the boundaries of Jasper National Park. The ski area plays an important economic role and supports many local businesses during the winter season.

Specific objectives of this risk assessment include: 1) determining the potential influence of skier and other visitor use on caribou use of habitat in and around the Whistlers Creek drainage, 2) determining the potential influence of ski area development proposals and egress routes on predation risk to caribou in Whistlers Creek, 3) identifying ecological thresholds and advising Parks Canada, as the responsible authority, on potential effectiveness of mitigation measures and management thresholds that should be considered to address potential impacts identified in the research, and 4) determining the implications of potential development and human use in the Whistlers Creek drainage to regional caribou population viability.

New ski area development in the Tres Hombres and Outer Limits areas could significantly increase the number of people in vicinity of the Whistlers Creek area. Tonquin caribou winter habitat selection, predominantly during the late winter, has already been reduced within a buffer of approximately 5 km of the presently developed area. This avoidance is not explained by predation risk, suggesting that late winter avoidance of Marmot Basin is a result of human activities. New developments within the Tonquin range could exacerbate current conditions, and therefor would not be consistent with the need for active recovery efforts to address threats to the rapidly declining Tonquin caribou population. In addition, mitigation measures should be implemented to reduce stress to more tolerant individual caribou located near Marmot.

Predation is the most important proximate factor in the decline of caribou populations in Jasper and Banff National Parks. The observed vulnerability of caribou to predation in late winter and spring, the close association of wolves with roads and trails found in this study, and the declining trend of the Tonquin population, suggest that mitigation measures to reduce predator access and efficiency should be a priority. This includes the closure of existing trails and/or restrictions on snow compaction that facilitates wolf travel in the range. New trails in caribou range could have population level effects by

increasing encounter rates and predation risk to caribou, and are not recommended at this time given the high level of risk currently assigned to the Tonquin population.

We estimated that current range disturbance for Tonquin caribou was between 16% and 22%, and applied criteria established for identification of critical habitat for boreal caribou (Environment Canada 2011; 2012) as a baseline to evaluate thresholds. This disturbance-based habitat assessment suggests that current range conditions are *likely* to maintain a self-sustaining population over time. However, the habitat-based indicator of population condition was not consistent with the available demographic information on population size and trend for Tonquin caribou. Specifically, annual population estimates show a decline since 2006 from 111 (92-186) to 54 (45-82) caribou in 2011, and the population component of critical habitat assessment recognizes that very small populations (<50) are vulnerable to stochastic events and phenomena, resulting in an especially low probability of persistence. As a result of applying the full set of scientifically-based decision rules, there is *considerable evidence* to categorize the Tonquin caribou range as *not self-sustaining*, consistent with recommendations to base the evaluation on the indicator that produces the highest risk or lowest probability of meeting the goal of maintaining a self-sustaining population and to adjust the integrated risk assessment to indicate cases where there might be an increased risk of extinction due to small population size. This conclusion also is consistent with objectives of the proposed Recovery Strategy for Woodland Caribou, Southern Mountain population, where populations with fewer than 100 individuals are not considered self-sustaining. Further, the proposed Recovery Strategy for Southern Mountain Caribou identifies all areas of high elevation winter and/or summer range as critical habitat, which would include all of Marmot Basin, and applies the management thresholds for disturbance from boreal caribou only in low-elevation portions of the range.

The uncertainty associated with applying the disturbance thresholds established for boreal caribou, the revised criteria for identification of critical habitat at high elevations for mountain caribou, and the current population status of Tonquin caribou, warrant limiting any activities that could result in the displacement of animals from parts of their range or the direct loss of critical habitat. Additional anthropogenic disturbance within the Tonquin caribou range could exacerbate conditions that are contributing to a declining population and result in destruction of potential critical habitat. New developments are therefore not consistent with population recovery objectives, and mitigation options for existing developments should be implemented. This assessment and related conclusions should be re-evaluated should there be a significant increase in the number of caribou in the Tonquin population or if science-based criteria for range disturbance thresholds are established for central mountain caribou populations.

Although the assessment of potential implications of Park trails and other infrastructure to caribou population viability was beyond the original scope of this risk assessment, the inclusion of all anthropogenic disturbances was necessary to estimate total range disturbance based on criteria from the Scientific Reviews. This analysis also provided perspective on the relative contribution of potential

developments in Whistlers Creek to Tonquin caribou population viability. Specifically, whereas the effects of the Marmot ski area appear mostly restricted to winter habitat loss and reduced habitat use, trail and road access contribute to both total range disturbance and increasing predation risk. Therefore, potential development and human use in the development area and the potential new ski lift should be viewed as the second most important contribution to population viability after the disturbance and predation risk associated with roads and trails.

The Tonquin population is the largest in South Jasper and as such can be considered vital to regional population viability. Trends for most surrounding mountain and boreal caribou populations are declining. Achieving self-sustaining populations in surrounding areas with high levels of industrial development and multiple stakeholders will be challenging. Recovery actions for caribou populations with ranges within Park boundaries are urgent and can inform and potentially influence the outcome of management decisions for surrounding populations. The recent decline in Tonquin caribou numbers to a critical level, the result of the threat assessment for the regional caribou (the central mountain group) as very high (Environment Canada 2014), and Parks Canada's mandate to maintain ecological integrity emphasizes the need to implement mitigations to reduce threats to critical habitat, reverse the declining population trend, and work towards the recovery goal of achieving self-sustaining populations in all local populations (Environment Canada 2014).

1.0 INTRODUCTION

1.1 Background

South Jasper National Park (JNP) caribou populations have declined significantly since the 1970s, presumably as a result of the interactions of climate and wildlife management practices that altered predator populations (Bradley and Neufeld 2010). Reducing unnaturally high predation rates is a key management strategy identified for recovering these caribou populations (Bradley and Neufeld 2010). Of the three south Jasper populations, the Tonquin population contains the greatest number of individuals and until 2008, was the only population that experienced a slight population increase (JNP Caribou Progress Reports). Since then, the population has declined annually and is currently estimated below 50 individuals (JNP pers. com.). While focusing on the immediate threat of predation to these small caribou populations is essential for their survival, levels of human activity and infrastructure within their ranges must also be managed to increase their long-term probability of persistence (Walker et al. 1987).

The Marmot Basin Ski Area, established in the 1960's, is located in the northeastern portion of the Tonquin caribou population range and within the boundaries of JNP. The ski area plays an important economic role and supports many local businesses during the winter season. The Tonquin population belongs to the Central Mountain Caribou Designatable Unit (COSEWIC 2011), and is presently listed as *Threatened* by the Committee on the Status of Endangered Wildlife (COSEWIC). More recently, the proposed Recovery Strategy for the Woodland Caribou, Southern Mountain Population (*Rangifer terandus caribou*) in Canada identified the threat level in Central Mountain populations as 'Very High' (Environment Canada 2014).The presence of a ski area within the range of a threatened caribou population presents management challenges to JNP officials whose mandate is to "foster public understanding, appreciation and enjoyment in ways that ensure the ecological and commemorative integrity of these places for present and future generations" (Canada National Parks Act 2000).

Development in national park ski areas is guided by the *Ski Area Management Guidelines*, updated in 2006. The primary goal of the guidelines is to provide land use certainty for the ski areas, the Canadian public, and Parks Canada. The Guidelines are based on a number of principles to guide long term ski area planning. The *Marmot Basin Ski Area Guidelines for Development and Use (hereafter Site Guidelines)* outlines how this direction is to be achieved at Marmot Basin.

Potential future initiatives proposed by Marmot Basin in the Site Guidelines include the development of a skier egress trail from the Tres Hombres off-piste area, and ski lifts in the Tres Hombres and Outer Limits areas. With respect to additional developments outside the presently developed ski area, the Site Guidelines state that certain new developments will be *considered* if there is substantial environmental gain within or adjacent to the leasehold (Site Guidelines, Section 3). As such, Marmot Basin has agreed

to a substantial leasehold reconfiguration whereby the Whistlers Creek area and surrounding up-slopes (Figure 2) be removed from the leasehold in exchange for consideration of these potential initiatives. Parks Canada considers this lease reduction (approximately 18% of the present area) to have potential to be of substantial environmental gain because it offers enhanced protection to valuable caribou habitat and an important goat mineral lick (Site Guidelines, Section 3).

The completion of this caribou risk assessment is a requirement specified in the Site Guidelines before Parks Canada will consider new developments in the Tres Hombres and Outer Limits areas in the context of a new Long-Range Plan for the ski area supported by an environmental impact analysis (Site Guidelines). Dr. Fiona Schmiegelow, Professor at the University of Alberta, was selected by both parties as the researcher to lead the risk assessment as per the *Caribou Risk Assessment Terms of Reference*. This report provides an unbiased overview of current conditions and potential risks of new developments to help guide the decision-making process. Related analyses were based on available information (i.e. no new data were collected to support this assessment). However, it is important to note that the information and data available were updated during the course of this assessment, with significant implications for the conclusions drawn here.

1.2 Relevant Literature Review

The World Bank (1997) identifies three types of disturbance in their guide to environmental impact assessments: direct, indirect, and cumulative effects. Here we summarize available literature pertinent to present and future potential developments within the Tonquin caribou range. These include direct disturbance by hikers, skiers, snowmobiles, and all activities associated with a ski resort that may cause caribou to actively move away once they encounter what they perceive to be a threat. Potential indirect effects include functional habitat loss as a consequence of caribou avoiding anthropogenic landscape change and infrastructure, and physiological stress that can have longer-term health consequences. We describe cumulative effects as the combination of identified winter and summer anthropogenic disturbances in the range. For the purpose of this report, we define disturbance as any deviation in an animal's behavior as a result of human influence (Frid and Dill 2002, Vistnes and Nellemann 2008). We note that the studies summarized in the following sections have been conducted on different types of caribou under varying circumstances. However, we also note that regardless of these differences, it is clear from the available literature that managing the level of disturbance within caribou ranges is central to ensuring long-term persistence of caribou populations, and thus some generalization may be warranted where specific studies are lacking.

Effects of Tourist Resorts

Several recent reviews summarize the effects of tourism and outdoor recreation on caribou/reindeer (Wolfe et al. 2000, Weladji and Forbes 2002, Reimers and Colman 2003, Vistnes and Nellemann 2008).

However, most North American studies identifying factors that may negatively affect caribou concentrate on resource extraction sectors (Nellemann and Cameron 1998, Cameron et al. 2005) because they have the greatest footprint on the landscape, and because many North American caribou populations are in areas that are of little value as tourism destinations. As such, the best information available on the potential effects of tourist resorts is found in research from Scandinavia, where resorts of various sizes are located within reindeer ranges. In an analysis of 10 alpine resorts, Nellemann et al. (2010) found that areas within 14 km from all resorts were used less than expected, and that the mean distance of individuals to the nearest resort increased with the size of the resort. There are two Scandinavian studies that directly measured the potential effects of ski resorts on reindeer (Helle and Sarkela 1993, Nellemann et al. 2000, Helle et al. 2012).

The holiday resort of Saariselka in Finland is located on the outskirts of a National Park. Initially geared towards wilderness-oriented users, the resort has evolved to offer activities such as slalom and cross-country skiing, hiking, and other outdoor activities, with approximately 200,000 overnight visits in 1983 (Helle and Sarkela 1993). An estimated 2500 semi-domesticated reindeer inhabited the 180 km^2 study area, 50% of which is within the Park. In 1983, researchers compared 3 zones delineated based on visitor numbers. Within these 3 zones, researchers conducted pellet transects, monitored sex-ratio, and measured vegetation coverage and lichen height. Generally, caribou avoided areas near cross-country ski trails in the forest in winter and used open-habitat on hilltops more than expected, possibly to maintain a safe distance from the disturbance (Helle and Sarkela 1993). Caribou avoidance was proportional to the intensity of the recreation. The sex ratio varied between zones and was increasingly male biased with increased tourist activity. Lastly, caribou foraging significantly reduced lichen height in zones closer to tourist activity.

The 3 zones were again monitored in 1986 and 2000 (Helle et al. 2012), during which time there was an increase in tourist activity. There were approximately 300,000 overnight visits in 1986 and this number doubled by 1993. Generally, results were similar to those observed in 1983, although female avoidance was observed up to 12 km in 1986 and only between 0-4 km in 2000, despite the increase in tourist activity. Authors suggest that this behavior could be a response to closures of 'unofficial' trails and better channeling of tourist activity.

The potential effect of a high-altitude resort located just outside the northwestern corner of Rondane National Park in Norway was investigated in March between 1991 and 1996 (Nellemann et al. 2000). Approximately 1500 wild reindeer have their winter grounds in northern Rondane. Researchers conducted systematic snowmobile surveys to monitor caribou presence around the resort and conducted vegetation surveys by sampling 27, 20 x 50 m sites within lichen heath communities. Results indicated that reindeer density increased with increasing distance from the tourist resort; no groups of animals were observed within 5 km of structures at the resort, and all females and calves avoided areas within 10 km of the resort. Maternal groups appeared most sensitive to disturbance and were primarily located 15-25 km from the resort. Lichen cover also decreased with increasing distance from the resort

and vegetation data indicated overgrazing as a result of reindeer redistribution away from the resort, and underuse of nearly 50% of the study area as a result of avoidance. Researchers suggest that winter grazing pressure and increased levels of anthropogenic disturbance may explain record low calf recruitment in the last 10 years. This study identified the 0-5 km zone as a critical tolerance distance to human infrastructure independent of human activity (Nellemann et al. 2000).

Effects of Skiers, Hikers, and Snowmobiles

Responses to a directly approaching human on foot or skis were experimentally evaluated for feral (Reimers et al. 2006) and wild (Reimers et al. 2003) reindeer in Norway. A single researcher approached reindeer and recorded specific behavioral responses. Season and group size had the largest effect on reindeer response (Reimers et al. 2006). Escape distance (the shortest straight-line distance from where the reindeer took flight to where the reindeer resumed grazing) was greatest in July, and caribou in smaller groups reacted from greater distances and moved farther than those in larger groups (Reimers et al. 2006). Animals generally retreated up-slope regardless of observer location or wind (Reimers et al. 2006), and escape distance was longer when reindeer were lying compared to grazing prior to provocation (Reimers et al. 2003). With the caveat that there will be a high degree of variation between situations, populations, and individuals, the authors suggest 'threshold safe distances' of 350 m for winter and summer and 200 m during the fall/rut season (Reimers et al. 2006).

Recreational snowmobiling is prohibited in Jasper National Park; therefore, the only anticipated contact between caribou and snowmobiles would be within the presently developed area and the potential egress route from proposed new developments. The direct behavioral responses of caribou and reindeer encountering snowmobiles are best documented in three controlled studies in Svalbard, Norway (Tyler 1991), Gros Morne National Park, Newfoundland (Mahoney et al. 2001), and the Coast Mountains, Yukon (Powell 2004). Studies approached animal groups at controlled speeds and noted the disturbance distance (DD, first sign of alarm) and distance at initial flight (DIF) while noting appropriate covariates. The disturbance distance ranged between 50 m and 1.3 km, whereas mean DIF ranged between 67 m and 282 m (Tyler 1991, Mahoney et al. 2001, Powell 2004). All studies found snowmobiles to alter the normal activity patterns of animals. Factors that influence the level of response to approaching snowmobiles include group size and composition (Powell 2004), speed and direction of approaching snowmobiles (Tyler 1991), behavior of drivers (Powell 2004, Kinley 2008), snow depth (Mahoney et al. 2001), sound emission (Powell 2004), visibility and terrain type (Simpson 1987), and animal behavior prior to provocation (Mahoney et al. 2001). Several authors suggest that the strength of measured responses can be attributed to habituation and the individual experiences of caribou with snowmobiles (Tyler 1991, Mahoney et al. 2001, Kinley 2008); however, Powell (2004) did not detect an effect of habituation to snowmobile exposure when comparing two areas with different levels of snowmobile use.

Avoidance of snowmobiles also was documented for mountain caribou near Revelstoke (Simpson 1987) and Prince George (Seip et al. 2007), British Columbia. With respect to direct provocation, sound alerted caribou and caused them to withdraw, human scent made them flee, and the sighting of humans elicited the least response provided that humans were not scented (Simpson 1987). Caribou generally moved less than 1 km immediately following disturbance by one or two snowmobiles and continued using the area within 2 km of the disturbance site (Simpson 1987). Both studies concluded that intensive snowmobile activity can displace caribou from high quality habitat (Simpson 1987, Seip et al. 2007). Caribou use of a ridge near Revelstoke declined substantially after construction of a chalet and increased use of the area by the Revelstoke Snowmobile Club (Simpson 1987), whereas intensive snowmobile activity resulted in complete displacement from an entire mountain block east of Prince George (Seip et al. 2007).

Physiologically, caribou exhibit a stress response to the presence of snowmobiles in an area (Freeman 2008). Specifically, fecal glucocorticoid levels in BC mountain caribou were greater in an area with snowmobiling and heli-ski activities than in an area where motorized recreation was not allowed (Freeman 2008). In addition, the stress response was detected up to 10 km from snowmobile activity. Although at present there is no evidence linking high stress hormone levels to caribou fitness, several studies have correlated chronic elevated stress hormone levels to individual survival and population declines in other species (Pride 2005, Blas et al. 2007, Cabezas et al. 2007, Ellenberg et al.2007).

Snowmobile trails also can have the indirect effect of creating hard packed travel corridors for predators (Neumann & Merriam 1972, Bloomfield 1979). Wolf predation is often responsible for adult mortality and low recruitment in caribou populations across Canada (Gasaway et al 1983, Stevenson & Hatler 1985, Bergerud & Ballard 1988, Seip 1991). Presently, most wolf related mortalities in JNP occur in late-winter (Whittington et al. 2011), and packed winter trails in the Tonquin range are located in the expansion area (Figure 2), the Cavell road after February 15th (early-winter closure since 2009-2010), and in the middle of the range for late-winter freighting of supplies by snowmobile over Maccarib Pass to 2 outfitter lodges.

Effects of Roads, Trails, and Noise

Present and potential linear features within the Tonquin range that could affect caribou include access roads to the ski area and adjacent parking lots, a new skier egress route, and hiking trails. There is substantial literature describing the impacts of roads on caribou, particularly with reference to oil field development (Cameron et al. 1992, Nellemann and Cameron 1996, James and Stuart-Smith 2000). The degree to which roads affect caribou is dependent on various factors, including, but not restricted to, the type of road, its purpose, the habitat types in the surrounding areas, the visual attributes of the road, habituation, and season of use (Wolfe et al. 2000). Traffic appears to be the most important predictor of the level of response exhibited by caribou and reindeer to roads (Wolfe et al. 2000, Reimers

and Colman 2003). However, caribou and reindeer avoidance of roads with very little or no human traffic has been detected at distances up to 5 km (Dau and Cameron 1986, Cameron et al. 1992, Vistness and Nellemann 2001). Dahle et al. (2008) found a 35% reduction in lichen cover within 8km of a highway and tourist cabins.

There is little quantitative information available describing caribou/reindeer avoidance of hiking trails, however; Skarin (2006) did find that reindeer were more likely to use summer habitat closer to hiking trails during the night when tourist traffic was lower, and were closer to hiking trails before the hiking season started than during the hiking season. At this finer scale, other studies have documented that caribou avoided and/or changed their behavior within buffer distances of 250 m of seismic lines (Dyer et a. 2001), 300 m of pipelines (Murphy and Curatolo 1987), and 1500 m of snowmobile tracks (Anttonen et al 2011).

Caribou movement and behavior can also be affected by the noise associated with various anthropogenic disturbances (Bradshaw et al. 1997), which could have significant energetic consequences depending on the number of perturbations (Bradshaw et al. 1998). The hearing capacity of humans is better than that of reindeer except at the highest frequencies, which suggests that sudden unpredictable noises could have a greater impact on animals than continuous noises (Flydal et al. 2001). Reindeer hear sound within the 70 Hz to 38 kHz range (Flydal et al. 2001) which means that they perceive most noises created by anthropogenic disturbance and human vocalizations (Reimers and Colman 2003).

Cumulative Effects and Caribou Population Viability

Clearly, different types of disturbances will elicit varying degrees of avoidance response by caribou and reactions may differ across seasons in a population (Polfus et al. 2011). These disturbances have the potential to behave cumulatively and can represent a significant anthropogenic footprint within a caribou range. Many studies have identified correlations between the level of total disturbance within a range and negative impacts on caribou/reindeer nutritional condition (Cameron et al. 2005), reproductive success (Nellemann and Cameron 1998, Nellemann et al. 2000, 2001), predation risk (Whittington et al. 2011), calf survival (Dussault et al. 2012), and local extirpation (Vors et al. 2007).

The mechanism(s) by which the level of anthropogenic disturbance within a range can affect population dynamics and viability can differ between areas, may be difficult to identify, and could change over time (Wittmer et al. 2006, Brown et al. 2007, Wittmer et al. 2010). Regardless of this uncertainty, it is clear that managing the level of disturbance within caribou ranges is central to ensuring long-term persistence of caribou populations. As such, we do not distinguish between seasonal disturbance levels because of the cumulative impact they exert on populations.

1.3 Risk Assessment Objectives

The overall purpose of this caribou risk assessment is to determine the potential effects of development in the Tres Hombres and Outer Limits areas of the Marmot Basin Ski Area. Specific objectives include (*Caribou Risk Assessment Terms of Reference)*:

1. To determine the potential influence of skier and other visitor use on caribou use of habitat in and around the Whistlers Creek drainage.
2. To determine the potential influence of ski area development proposals and egress routes on predation risk to caribou in Whistlers Creek.
3. To identify ecological thresholds and advise Parks Canada, as the responsible authority, on potential effectiveness of mitigation measures and management thresholds that should be considered to address potential impacts identified in the research.
4. To determine the implications of potential development and human use in the Whistlers Creek drainage to regional caribou population viability.

To achieve these objectives, we first describe seasonal habitat selection patterns of female caribou within the Tonquin range, in order to quantify habitat quality within the presently developed, Whistlers Creek, and expansion areas. We use available wolf locations to quantify seasonal predation risk to caribou within these areas, and then assess the seasonal impact of Marmot Basin activities on habitat selection by caribou. Next, we use this information to calculate summer and winter zones of influence of human activity on caribou in the Tonquin range. Finally, we combine all quantified effects to calculate a total disturbance value for the Tonquin range and discuss implications to population viability.

2.0 GENERAL METHODS

2.1 Choice of Scale

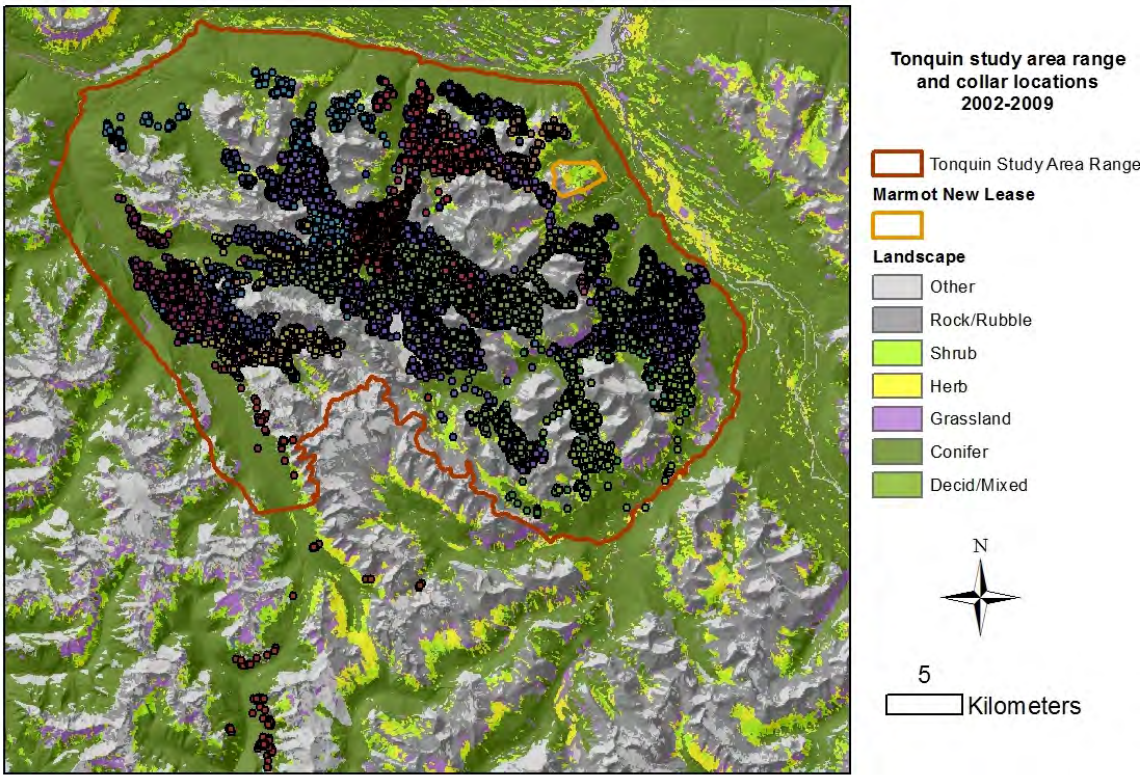
The majority of caribou disturbance studies in the 1970s and 1980s focused on local behavioral effects on individual animals, and most of these studies concluded that the effects of disturbance were few and short-term (Vistnes and Nellemann 2007). However, many of these studies neglected to account for the fact that animals near infrastructure often represent the most tolerant segments of the population (Cameron et al. 1992, Nellemann et al. 2000). Although local impacts of disturbance to individual caribou (i.e. direct encounters with skiers and snowmobiles) should be mitigated, focusing on these effects alone would underestimate regional impacts (Vistnes and Nellemann 2007). For example, in their review of human activity on reindeer and caribou, Vistnes and Nellemann (2007) found that 83% of regional studies found significant impacts whereas only 13% of local studies concluded that animals were significantly affected by disturbance.

The Scientific Review for the Identification of Critical Habitat for Boreal Caribou (2008, hence Scientific Review) concluded that the *population range* is the relevant scale for the identification of critical habitat to support self-sustaining populations. The report defines the range as "the geographic area occupied by individuals of a local population that are subjected to the same influences affecting vital rates over a defined time frame". To estimate the potential effects of the expansion of Marmot Basin within the PC context of maintaining ecological integrity, we believe it most appropriate to use caribou habitat selection at the range scale as a reference for patterns observed within specific research areas near Marmot Basin.

2.2 Defining the Tonquin Range

We defined the Tonquin range study area (1,051 km^2) using available radio-collar data from 2002 to 2009 and biophysical features of the region (Figure 1). We believe this approach to be more appropriate than defining available habitat for the range using a Kernel or Minimum Convex Polygon, that would have included areas never used by the population. Specifically, there were no caribou locations below 1,200m; therefore, we used this elevation to delimit the north and east sides of the perimeter to avoid inclusion of the wider valleys where there were no collar data. We used the Whirlpool River to bound the southeast of the study area. There is no historical evidence of caribou using the Simon Creek drainage, although older locations are available further south of this drainage, and of our defined study area. Because there were few GPS radio-collar locations available south of Simon Creek, we chose to exclude the drainage and use the rock/ice elevational limit of 2400m to define the southern limit of the study area. Lastly, because caribou have been observed west of the Frazer River, we defined the western limit of the study area by buffering the river by 2 km. One hundred and two of the 72,830 collar locations (<1%) fell outside the delimited range and were excluded from analyses.

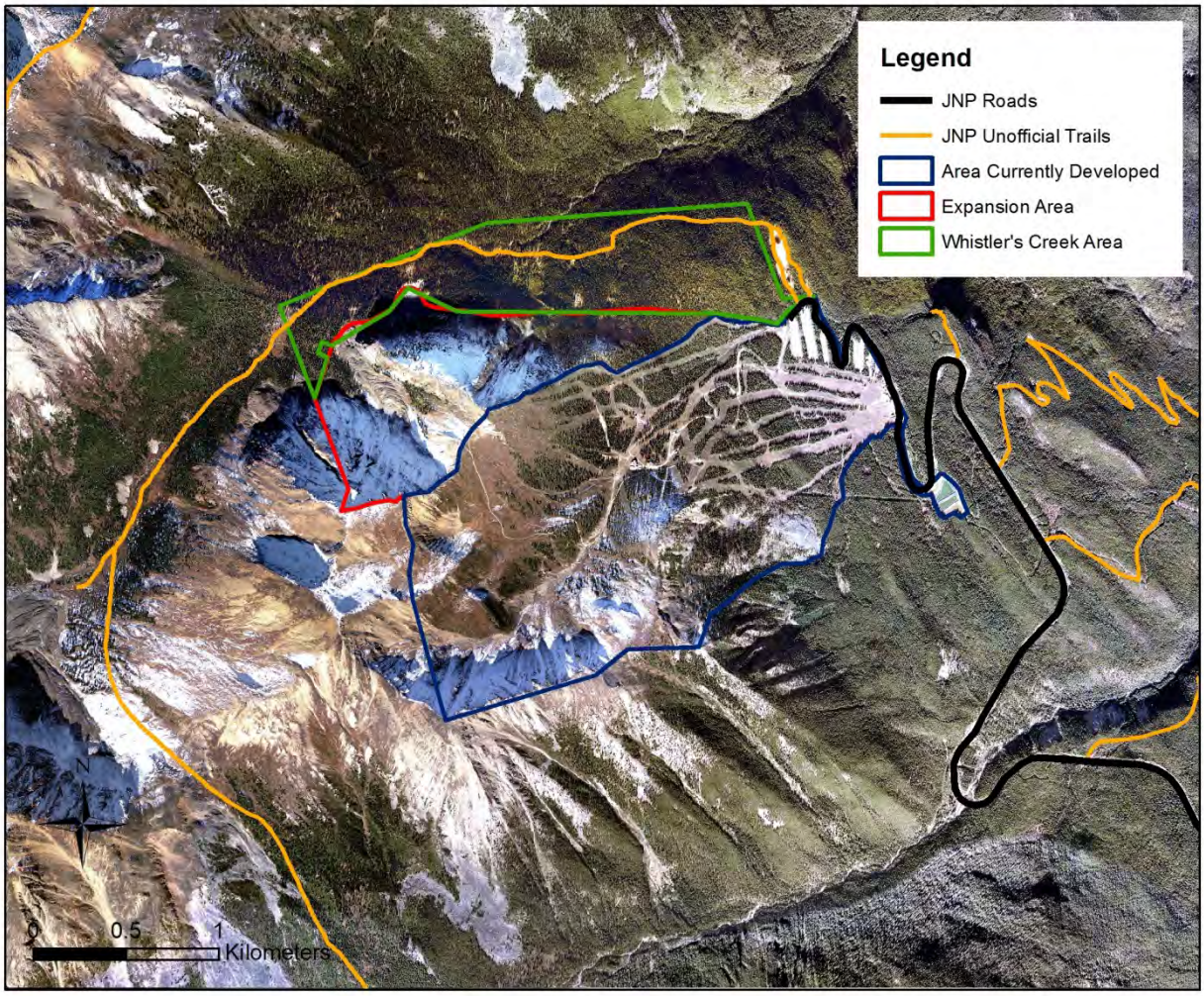
Figure 1. Tonquin Caribou range and female caribou collar locations (2002-2009).



2.3 Specific Research Areas

The research areas quantified for the purpose of this risk assessment include the area presently developed by Marmot Basin, the Whistlers Creek area removed from the Marmot leasehold (see section 1.1), and the Tres Hombres and Outer Limits areas. For simplicity, we henceforth refer to these areas as the Developed Area, Whistlers Creek Area, and the Expansion Area (Figure 2).

Figure 2. Risk Assessment study areas in the Tonquin caribou range.



2.3 Caribou Data

Our original dataset contained 72,728 GPS collar locations, from 15 female Tonquin caribou, from 2002 to 2009 (Table 1). Capture and collaring details are available in annual progress reports available from Parks Canada. Population data on size and trend were current to 2011.

Table 1: Seasonal GPS collar data available for analysis (Tonquin caribou 2002-2009).

	Date				
Season	Start	End	Duration (days)	Weeks	Num. Locations
Calving	23-May	20-Jun	29	22-25	5,429
Post-Calving	21-Jun	19-Jul	29	25-30	5,084
Summer	20-Jul	26-Sep	69	30-39	11,748
Rut	27-Sep	31-Oct	35	39-44	5,489
Early Winter	1-Nov	21-Jan	82	44-3	17,593
Late Winter	22-Jan	22-May	120	3-22	27,385
				Total:	72,728

Seasons were established based on information from Parks Canada staff (Mark Bradley, pers. com.) and are consistent with observed movement and elevational migrations. Tonquin caribou exhibited increased movement and use of higher elevations during snow-free months.

All caribou location data are from female caribou. Throughout the document, we omit the female designation for ease of readability, however, it is important to note that male and female caribou can exhibit different selection patterns throughout the year (Barboza et al. 2001) and that male selection is not accounted for in these analyses.

3.0 SPECIFIC METHODS AND RESULTS

3.1 Caribou base models

Rationale and Methods

Base seasonal habitat models are critical to quantifying the potential impacts of Marmot Basin expansion into the Tres Hombres and Outer Limits areas. These models represent the “mean” habitat selection observed from 2002-2009 and are used as a reference for more specific analyses. Seasonal base habitat models provide a measure of the perceived habitat quality within different areas of the Tonquin Range. We use weighted distributions to estimate Resource Selection Probability Functions (RSPFs) in the case of the use-available design (Lele and Keim 2006, Lele 2009). An RSPF is a function

that describes the probability that a particular resource, as described by a series of environmental covariates, will be selected by an individual animal (Manly et al. 2002). We assume that areas of high selection are biologically important and identify high quality habitats (Railsback et al. 2003). Models presented here may differ from other models generated for the Tonquin population because the purpose of this project was to predict, on average, the seasonal 'quality' of study areas within the Tonquin range as perceived by the animals. The small size of the study areas with respect to the range requires robust models with covariates of biological significance. As such, the study area was divided into five main landscape categories:

1. Cool moist lower subalpine lodgepole pine
2. Lower subalpine Englemann spruce and subalpine fir
3. Upper subalpine spruce, subalpine fir and larch
4. Non-forested lands with rarely burned vegetation
5. Rock/ice

Details of other landscape characteristics considered in models, statistical analyses, and individual caribou variation are provided in Appendix 1 of this report.

Results

Calving

Caribou habitat selection during the calving season was predominantly characterized by selection for higher elevation alpine and secondly upper subalpine habitats. In addition, caribou selected for areas closer to forest edge, which were associated with the non-forested/upper subalpine boundary. As such, caribou selected for elevations between 1700m and 2500m. Within these areas, selection was greatest for flat terrain and west facing slopes of up to 20 degrees (Figure 3).

Post Calving

During the post-calving season, caribou selected almost exclusively for large patches of alpine habitat between 2000m and 2500m and avoided all other vegetation classes. Alpine patch size was the strongest predictor of caribou habitat selection. Caribou selected predominantly for 10 degree south facing slopes and then for flat terrain (Figure 4).

Summer

During the summer season, caribou selected exclusively for large patches of alpine habitat between 2,000m and 2,500m and avoided all other vegetation classes. Caribou selected predominantly for flat terrain and then for south or west-facing slopes of up to 20 degrees. In addition, caribou selected for areas within 5km of linear features (Figure 5).

Rut

During rut, caribou selected for large patches of alpine habitat at elevations between 2,200 and 2,500m that were close to linear features, and avoided all other habitat types. Alpine patch size and distance to linear features were the strongest predictors of caribou habitat selection. Caribou avoided east facing slopes but were just as likely to be on flat terrain or slopes of up to 20 degrees on other aspects (Figure 6).

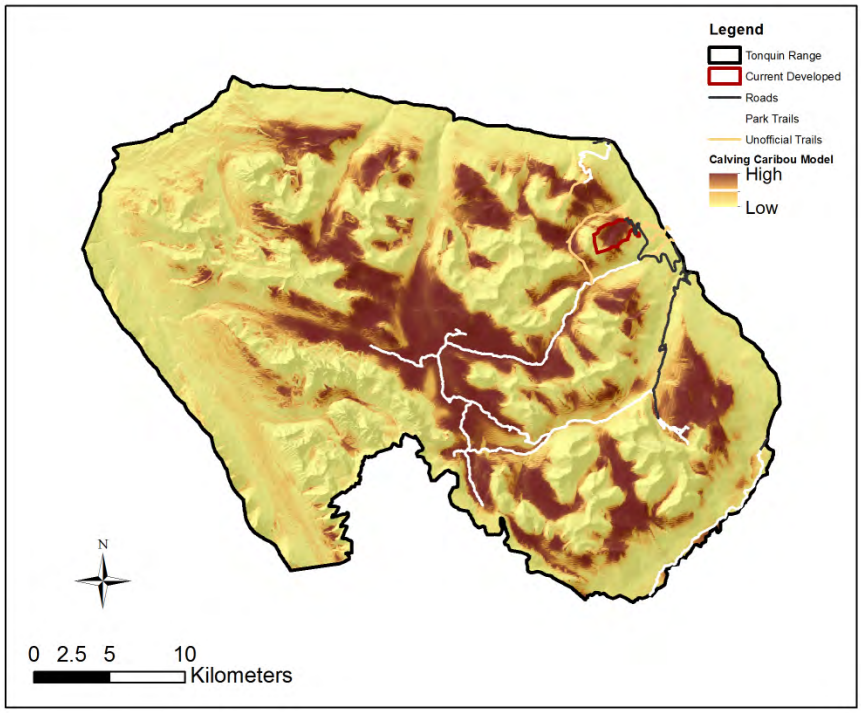
Early winter

In early winter, caribou selected primarily for 200 year old upper subalpine forest, secondly for alpine habitat (with no selection for patch size), and selected for both lower subalpine classes equal to availability. As such, caribou selected for elevations between 1,800m and 2,200m and exhibited greater selection for lower elevations within this range. Within these habitats, caribou selected predominantly for flat terrain and then for west facing slopes of up to 30 degrees (Figure 7).

Late winter

In late winter, caribou selected for all vegetation classes and avoided only the '*other*' class which consists primarily of rock/ice and waterbodies. Selection was greatest for the upper subalpine class and then similar for other vegetation types. Caribou selection was greatest for west facing slopes of up to 30 degrees and flat terrain was avoided (Figure 8).

Figure 3. Tonquin caribou habitat selection during the calving (May 23rd to June 20th) season 2002-2009.



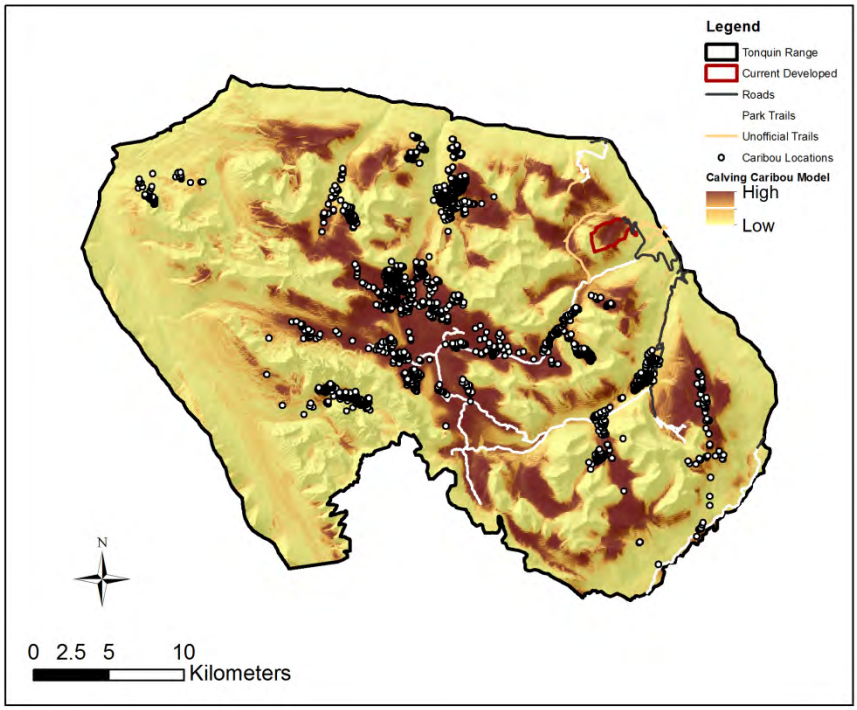
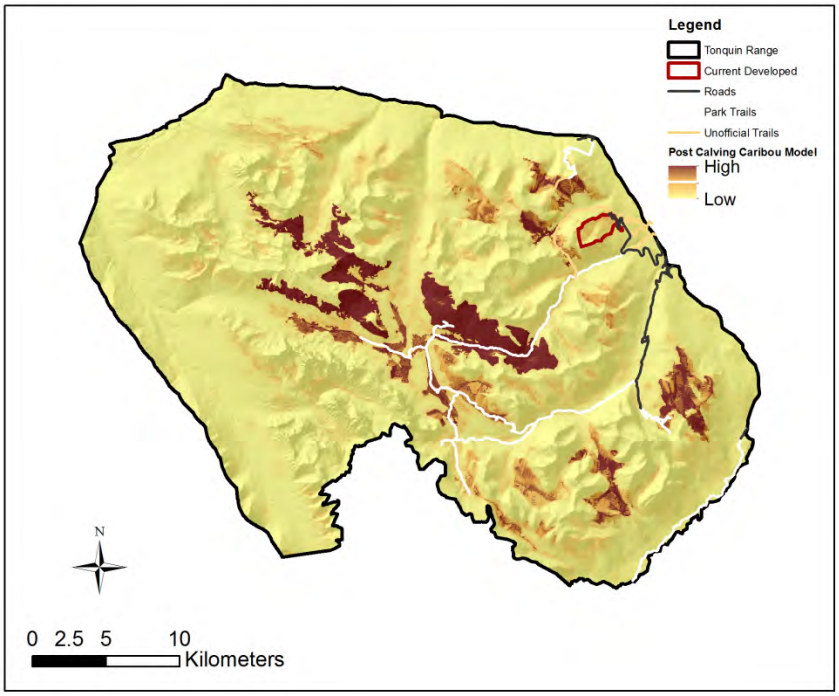


Figure 4. Tonquin caribou habitat selection during the post calving (June 21st to July 19th) season 2002-2009.



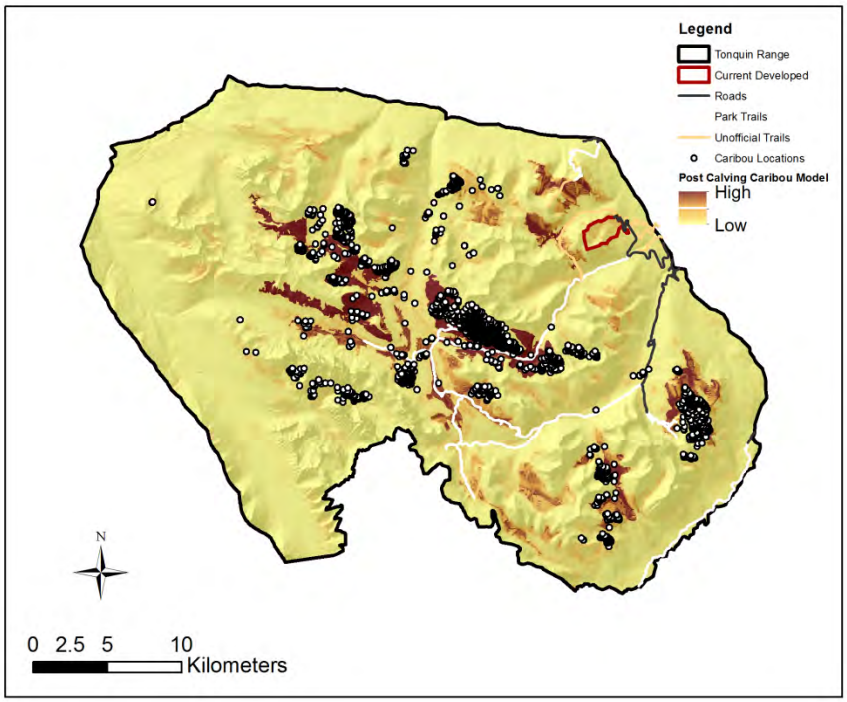
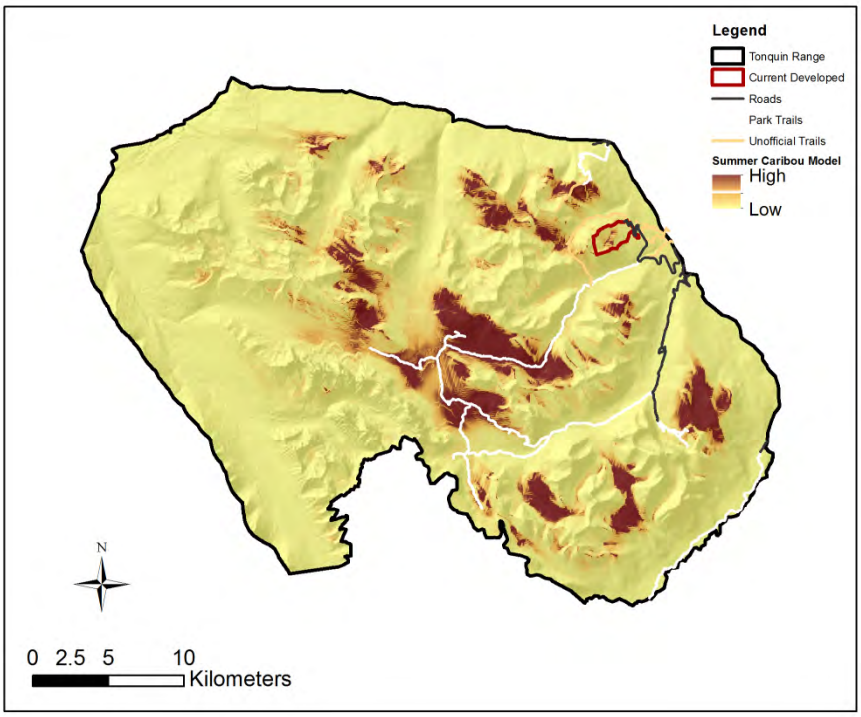


Figure 5. Tonquin caribou habitat selection during the summer (July 20th to September 26th) season 2002-2009.



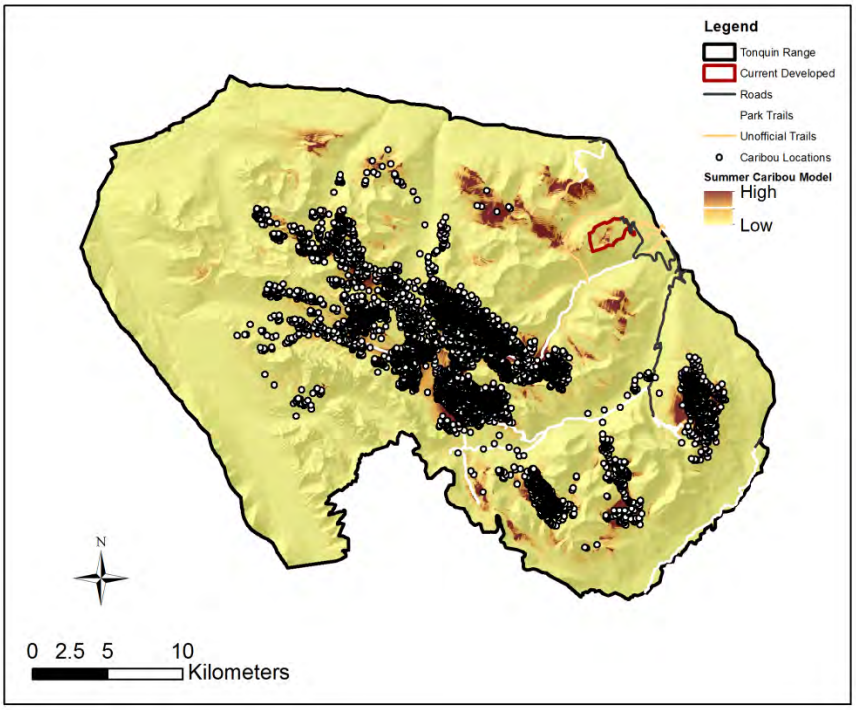


Figure 6. Tonquin caribou habitat selection during the rutting (September 27th to October 31st) season 2002-2009.

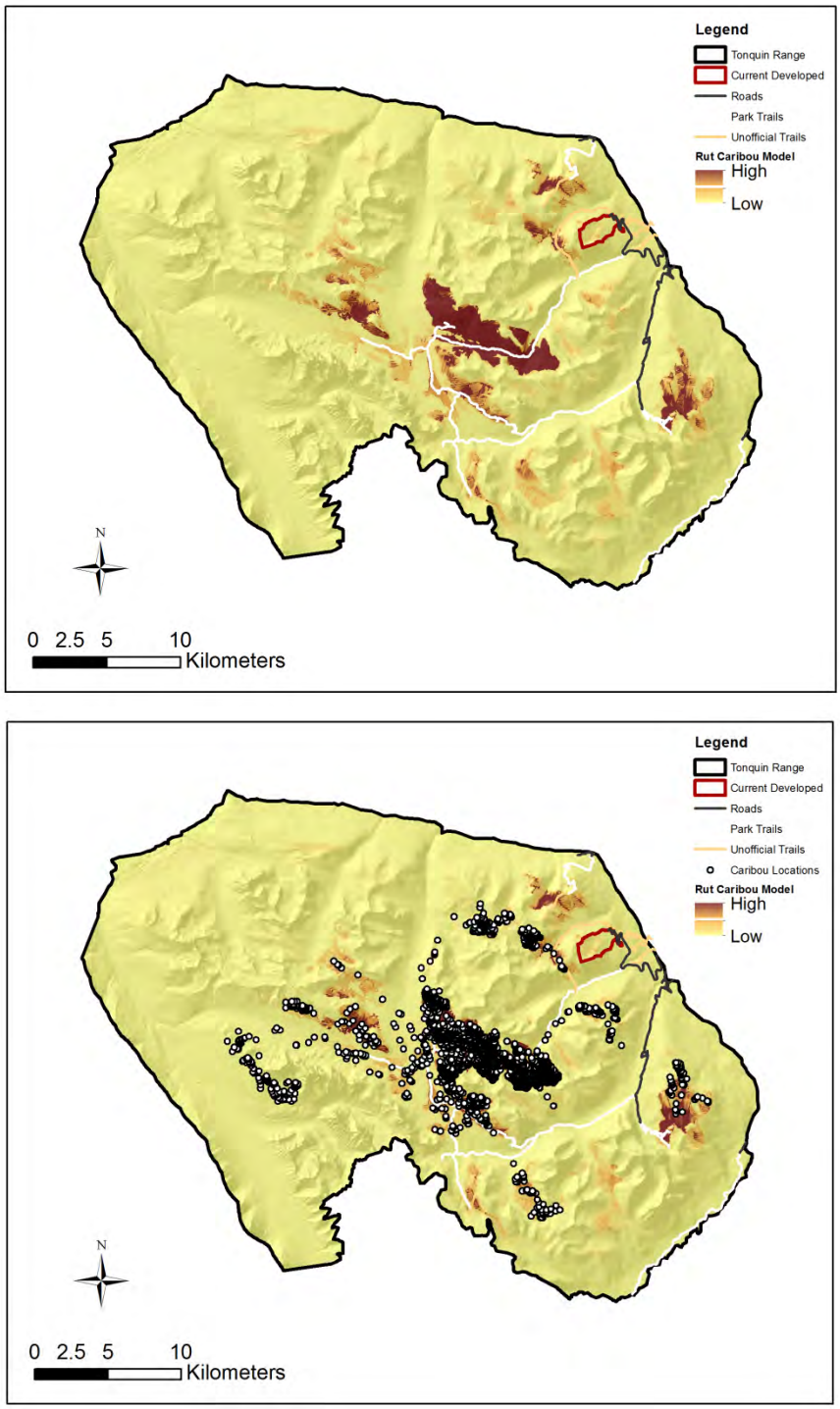
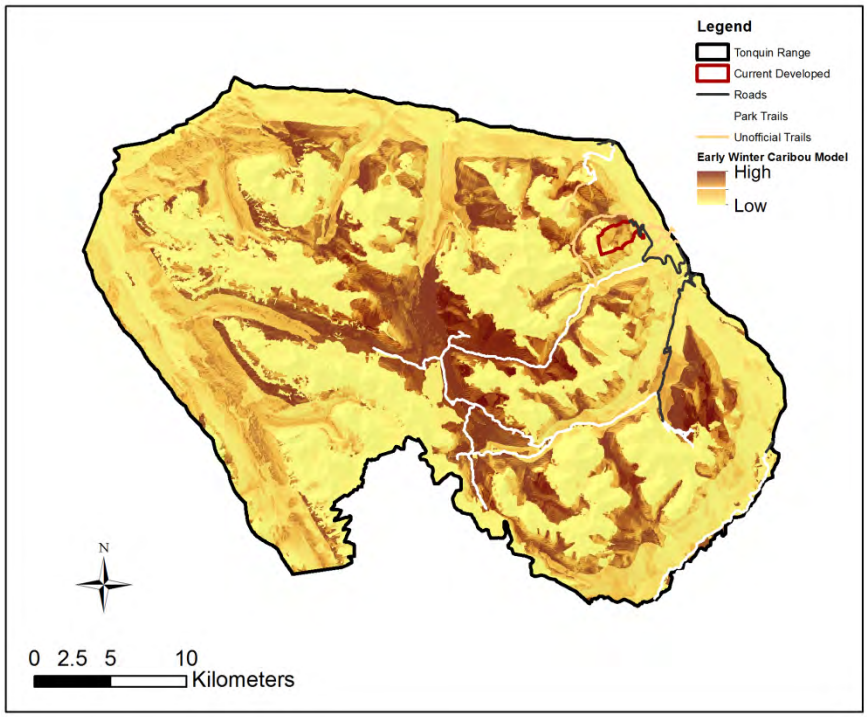


Figure 7. Tonquin caribou habitat selection during the early winter (November 1st to January 21st) season 2002-2009.



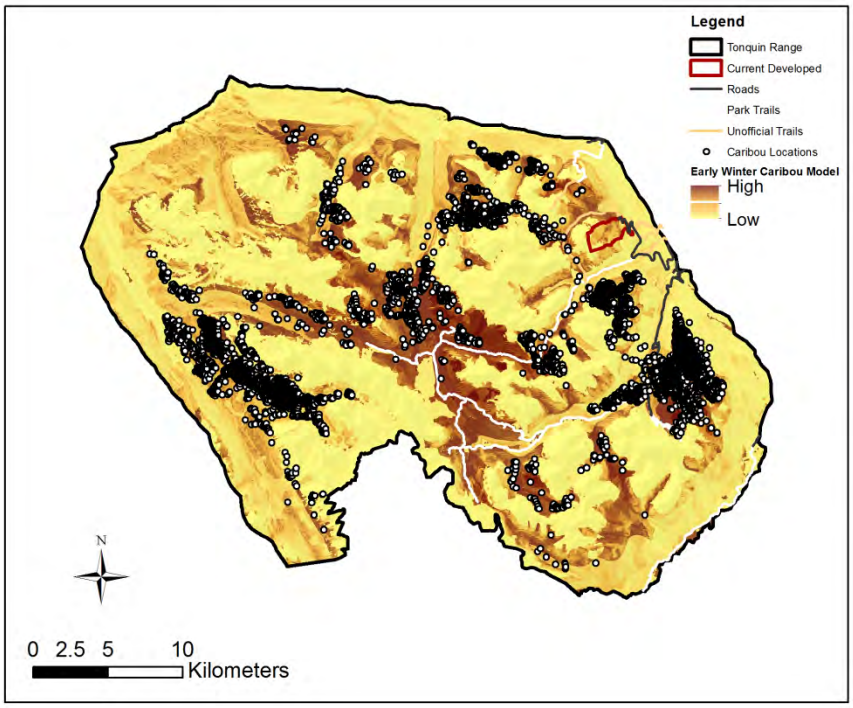
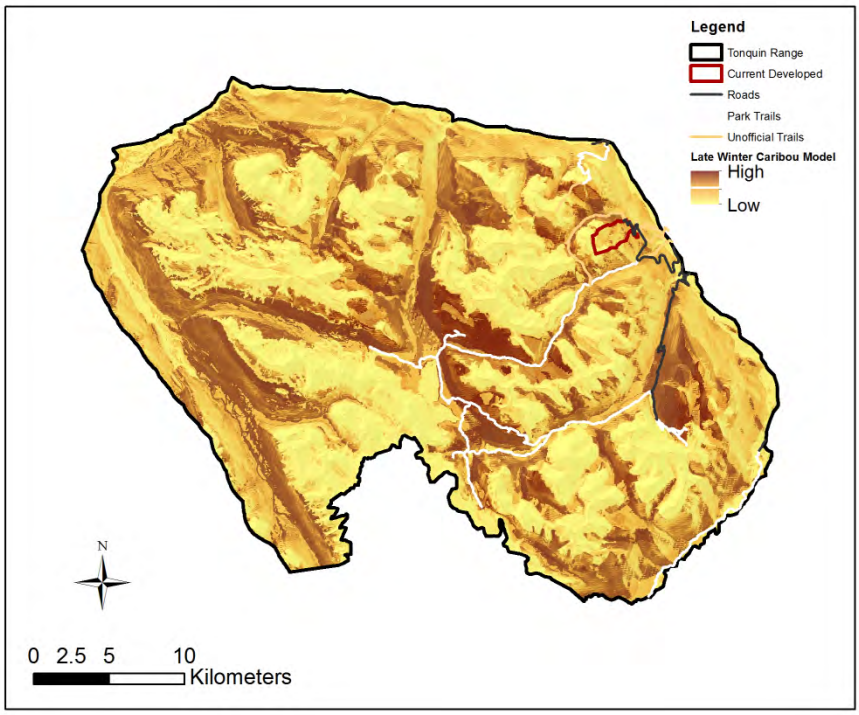
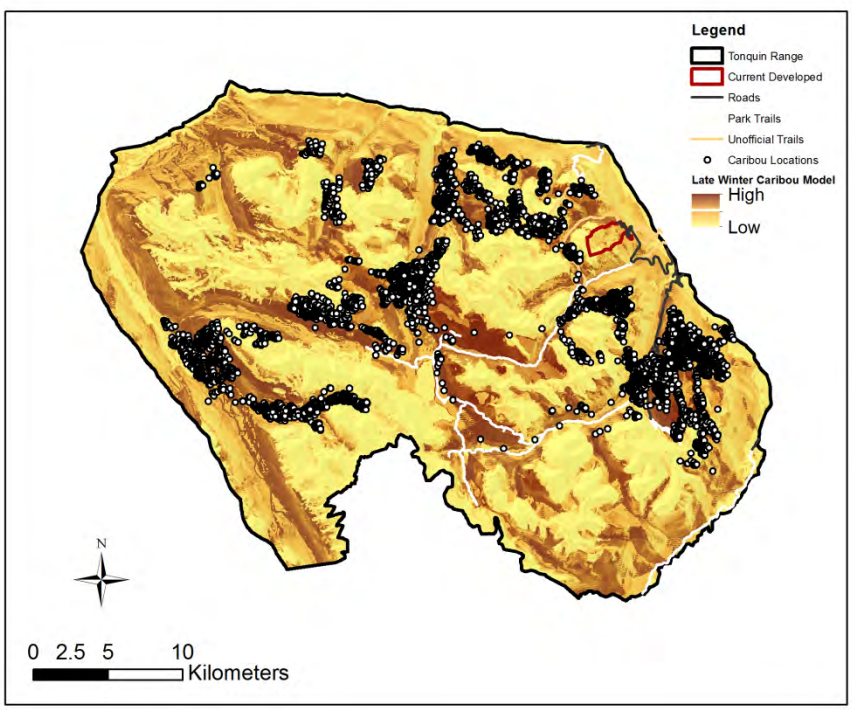


Figure 8. Tonquin caribou habitat selection during the late winter (January 22nd to May 22nd) season 2002-2009.





3.2 Potential effects of ski area development on habitat selection

3.2.1 Quantifying Caribou Seasonal Habitats in Study Areas

Rationale and Methods

Jasper National Park is considering new developments in the Expansion Area in exchange for removing the Whistlers Creek area from the Marmot Basin leasehold (Figure 2, see section 1.1 for details). Here, we describe the potential seasonal quality of each study area with respect to the range. This analysis quantitatively compares the relative 'value' of each study area in each season to identify if study areas contain seasonal habitat profiles that are disproportionally of greater or lesser selection values than those available over the entire range.

We described the value of seasonal habitats in each study area in 3 ways. We first divided the range of seasonal Tonquin selection values into 5 classes based on an equal interval classification to portray an accurate representation of the perceived 'quality' of various areas to caribou. Specifically, depending on how selective caribou are, and how common highly selected habitats are on the landscape, the distribution of selection values can be skewed.

Secondly, we identified the spatial distribution of highly selected habitats by highlighting the spatial distribution of the 3 highest-value classes over the Tonquin range. Lastly, we used the range histograms as a reference to compare the seasonal snapshots of selection values in study areas to those of the entire range. We quantified the quality of reference areas by clipping research area polygons from the binned range seasonal models.

Results

At the range scale, Tonquin caribou were more widely distributed across habitat types and more likely to select a greater proportion of their range during the winter seasons. Conversely, caribou were most selective for specific habitat types during the snow-free seasons, and preferred areas were highly transected by park hiking trails (Figures 9-15).

At the scale of the study areas, the currently developed ski area contained a higher proportion of high quality calving and post calving habitats compared to the distribution across the range (Figure 16). In addition, the area also contained a higher than average distribution of mid-quality early and late winter habitats. During remaining seasons, the developed area generally contained distributions of preferred habitats in proportions similar to those across the range.

In comparison, the distribution of winter habitat quality in the expansion area was relatively similar to that across the range in early and late winter, with a lesser proportion of most selected habitats in late

winter (Figure 17). The distributions of selected habitats in other seasons were relatively similar to the range though mid-range habitats were slightly better represented during the calving season.

The Whistler's Creek area contained a greater proportion of highly selected caribou habitats than their range distribution during the calving and winter seasons (Figure 18). This pattern was most apparent in early and late winter where approximately 90% of the area was classified in bins 4 and 5.

Figure 9. Seasonal distributions of Tonquin range habitat values from final RSPF models based on caribou locations from 2002-2009. Classes represent habitat values assigned to equal intervals.

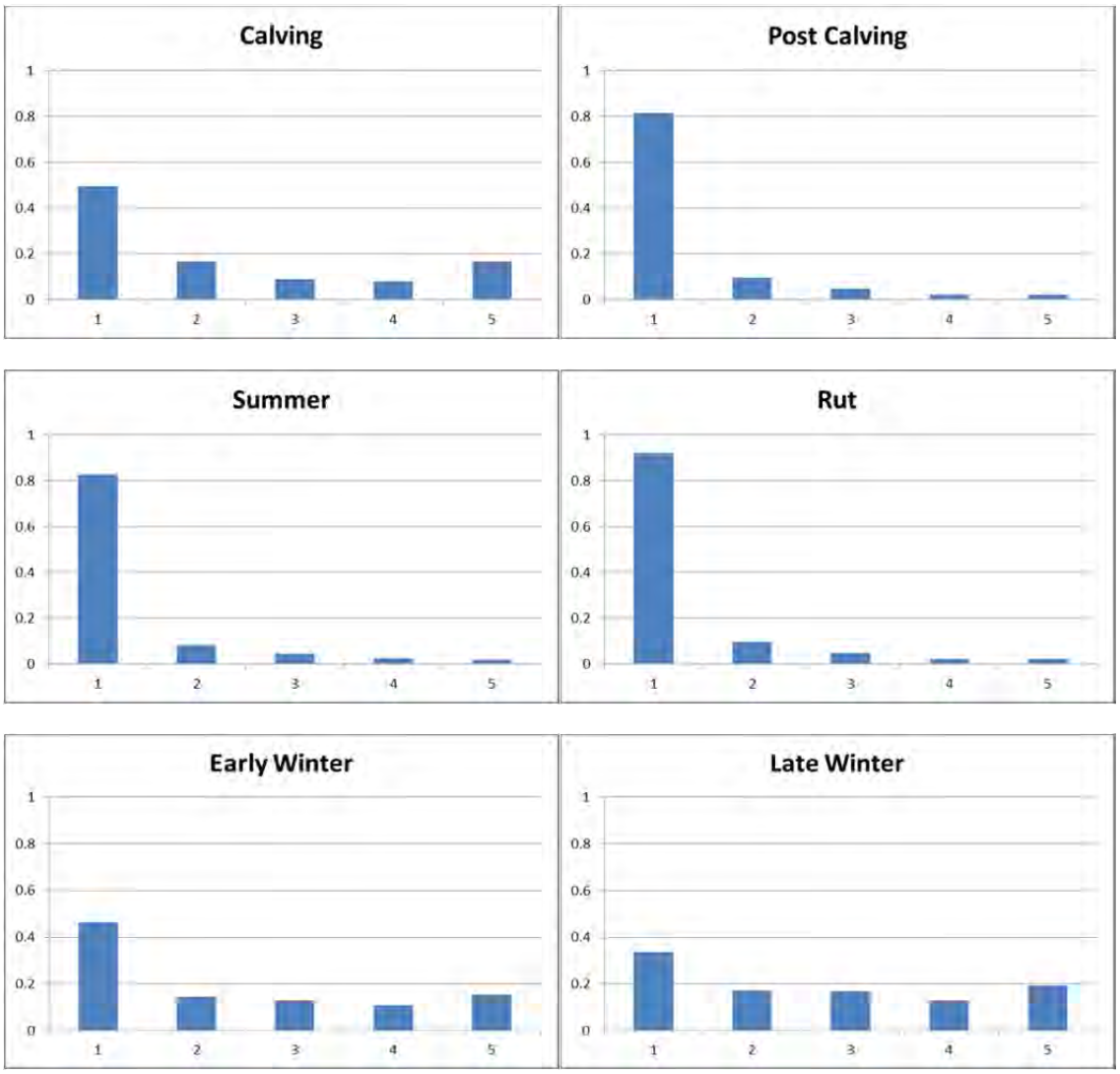


Figure 10. Spatial representation of habitat classes 3,4, and 5 during the calving (May 23rd to June 20th) season 2002-2009.

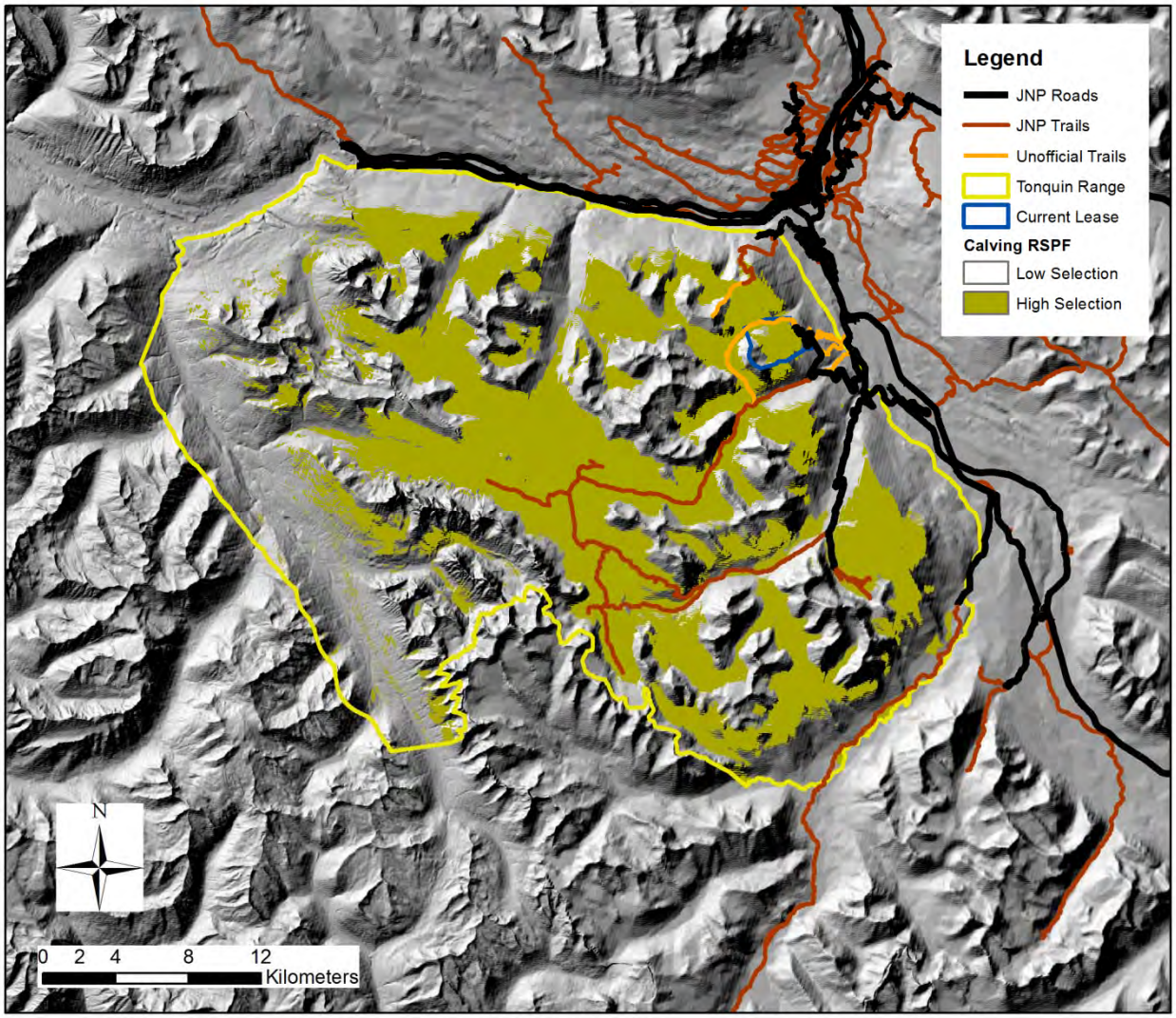


Figure 11. Spatial representation of habitat classes 3, 4, and 5 during the post calving (June 21st to July 19th) season 2002-2009.

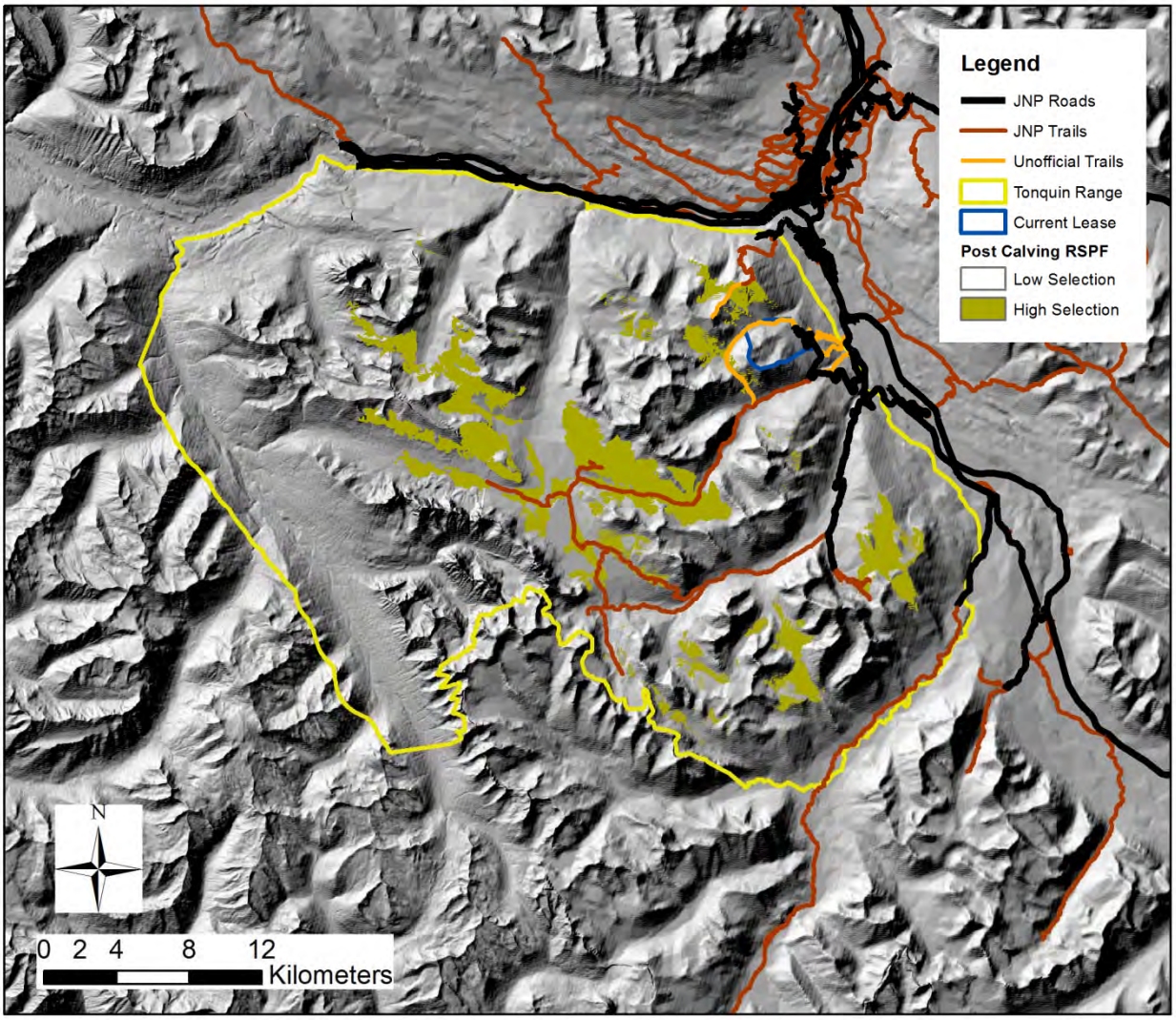


Figure 12. Spatial representation habitat classes 3, 4, and 5 during the summer (July 20th to September 26th) season 2002-2009.

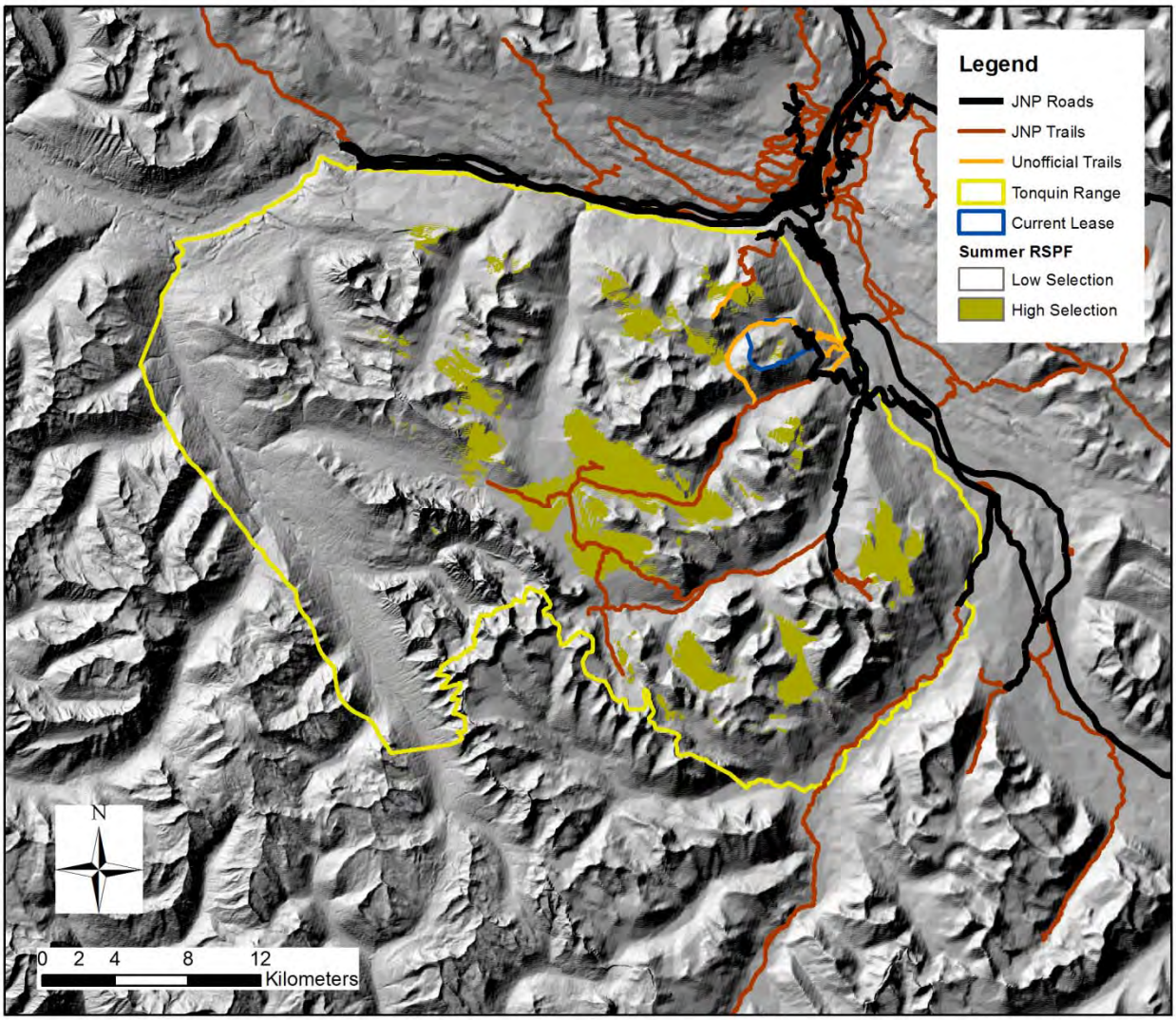


Figure 13. Spatial representation of access and habitat classes 3, 4, and 5 during the rutting (September 27th to October 31st) season 2002-2009.

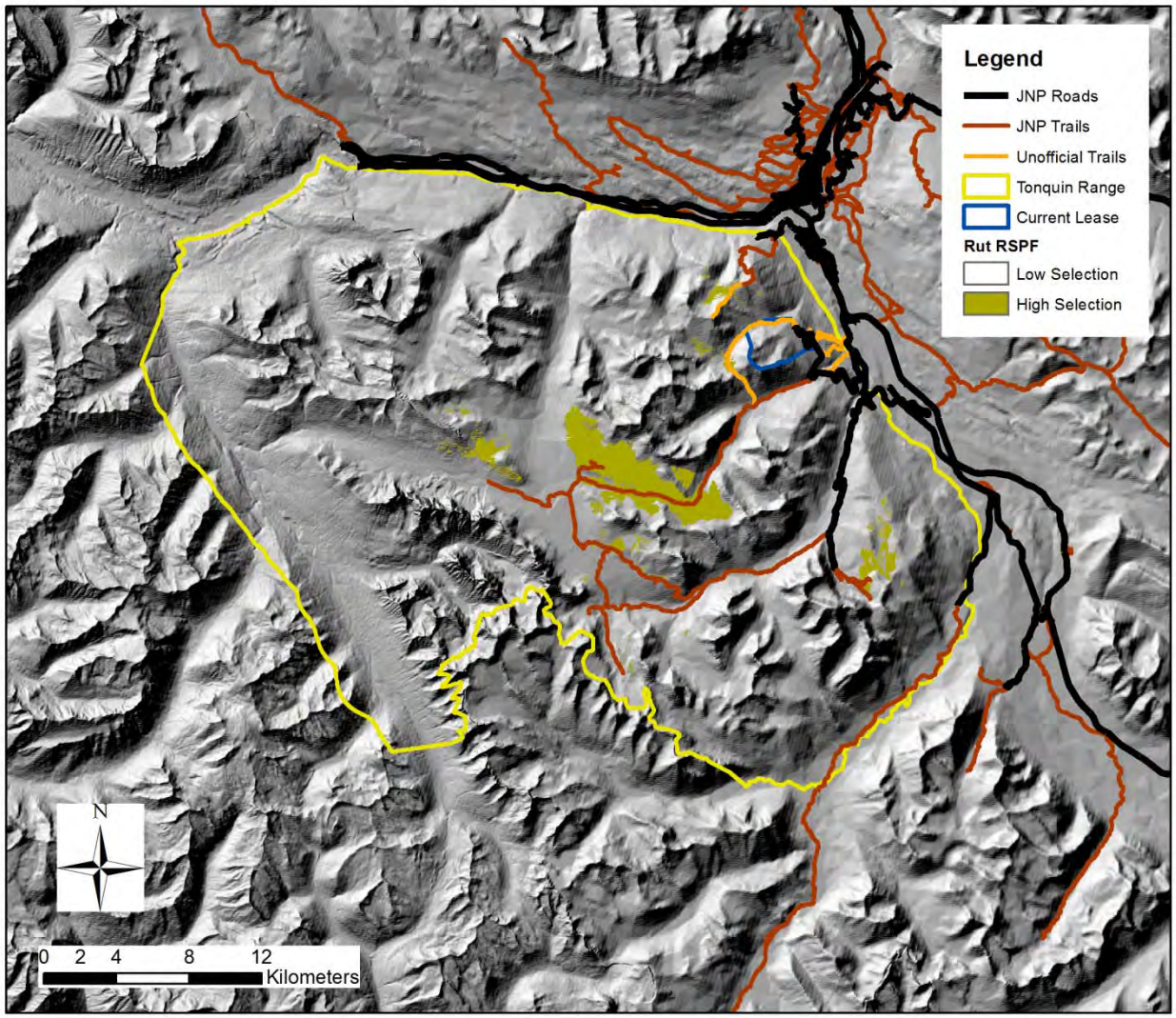


Figure 14. Spatial representation of access and habitat classes 3, 4, and 5 during the early winter (November 1st to January 21st) season 2002-2009.

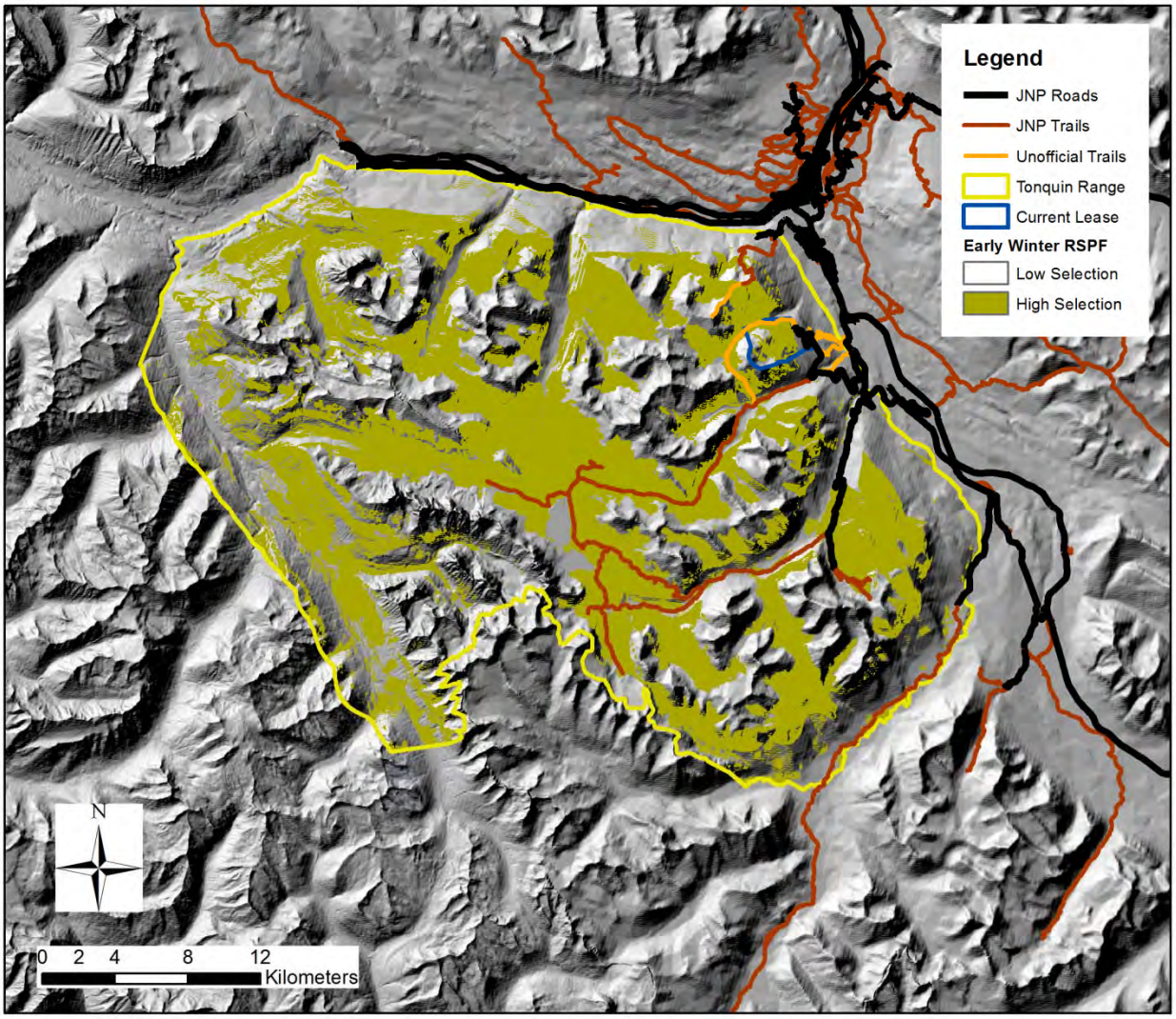


Figure 15. Spatial representation of access and habitat classes 3, 4, and 5 during the late winter (January 22nd to May 22nd) season 2002-2009.

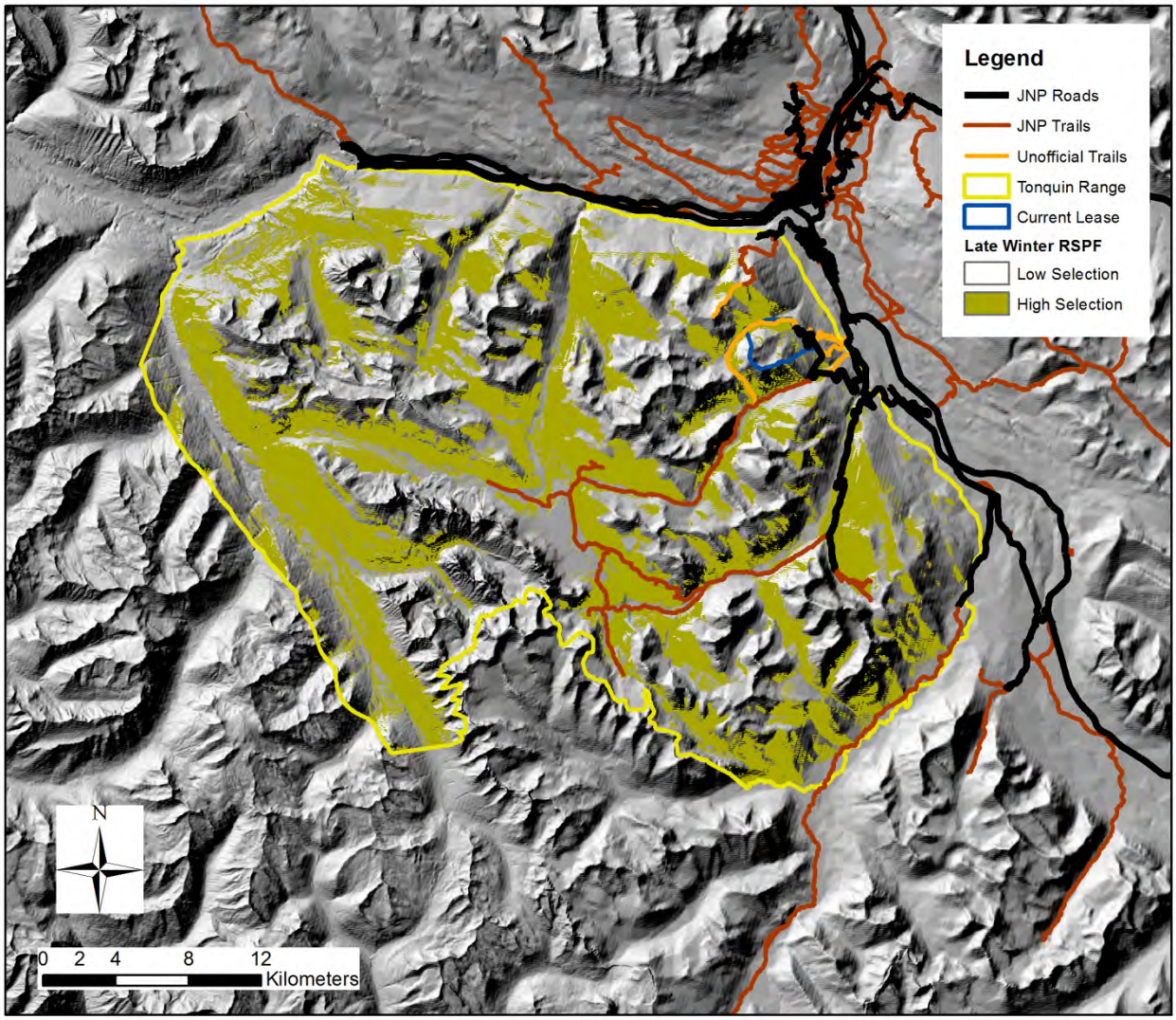


Figure 16. Seasonal distributions of base model habitat values from final RSPF models in the Tonquin Range (blue) and the currently developed Marmot Basin Ski Area (black), based on caribou locations from 2002-2009. Classes represent habitat values assigned to equal intervals.

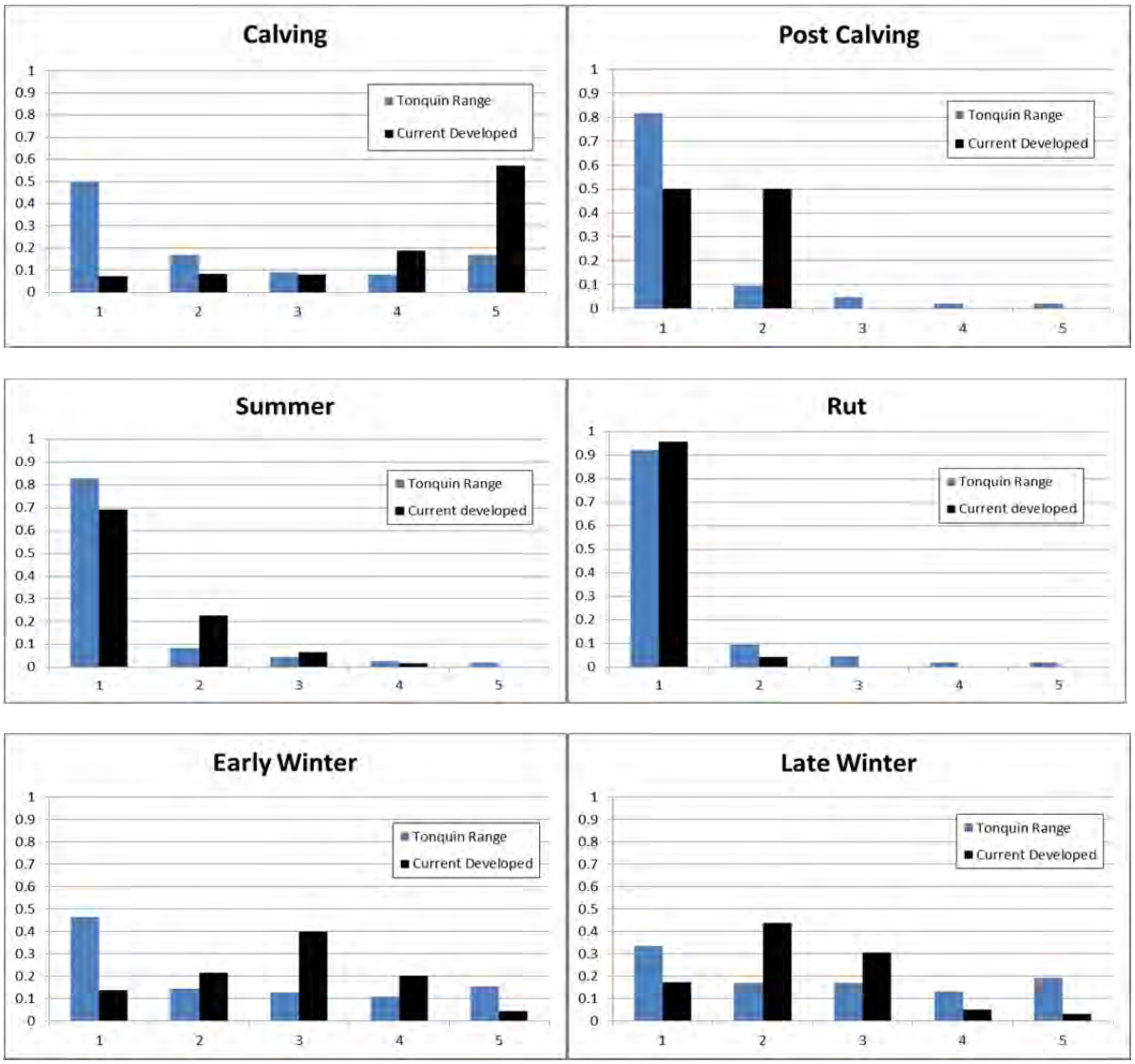


Figure 17. Seasonal distributions of base model habitat values from final RSPF models in the Tonquin Range and the Expansion Area based on caribou locations from 2002-2009. Classes represent habitat values assigned to equal intervals.

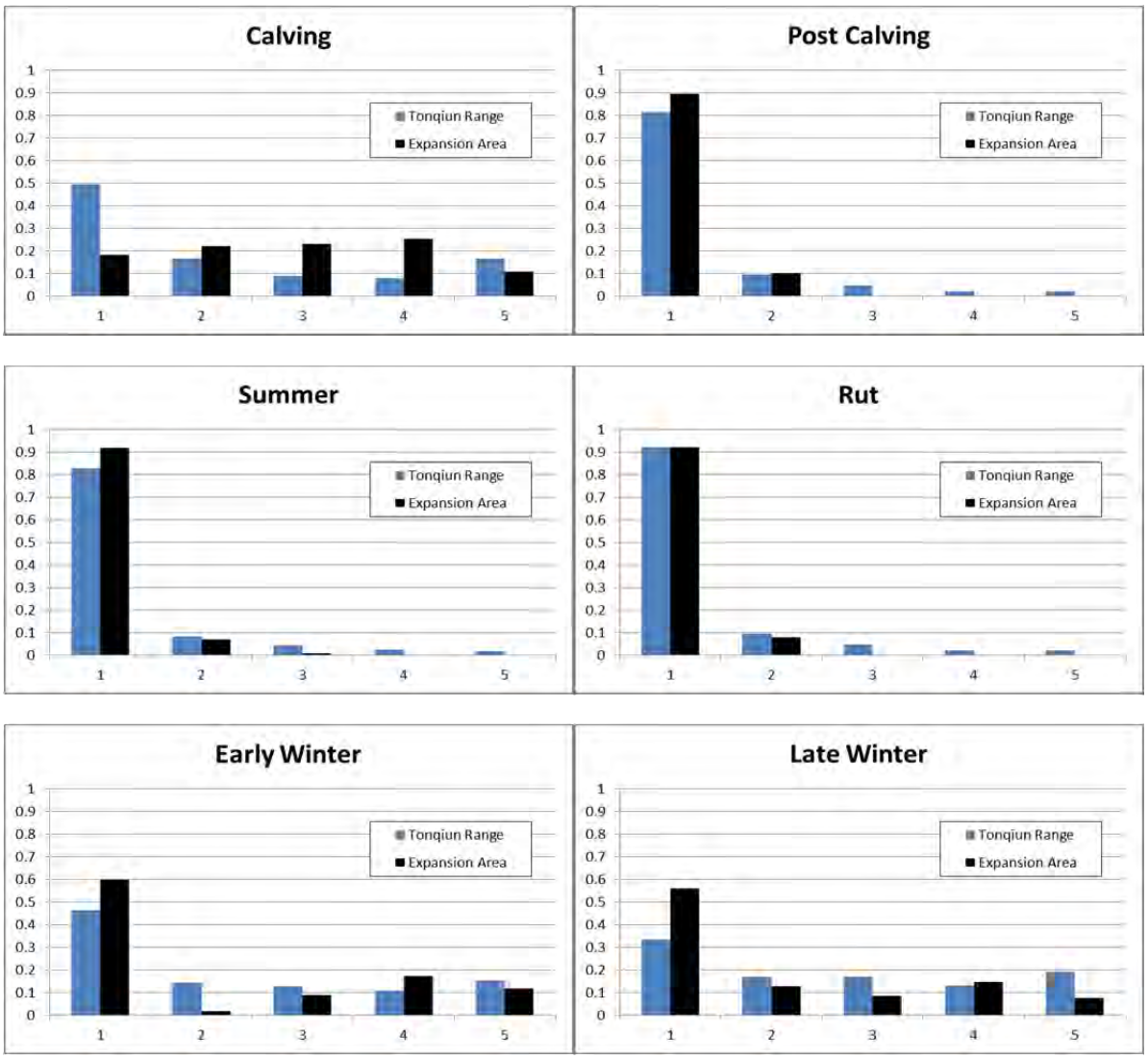
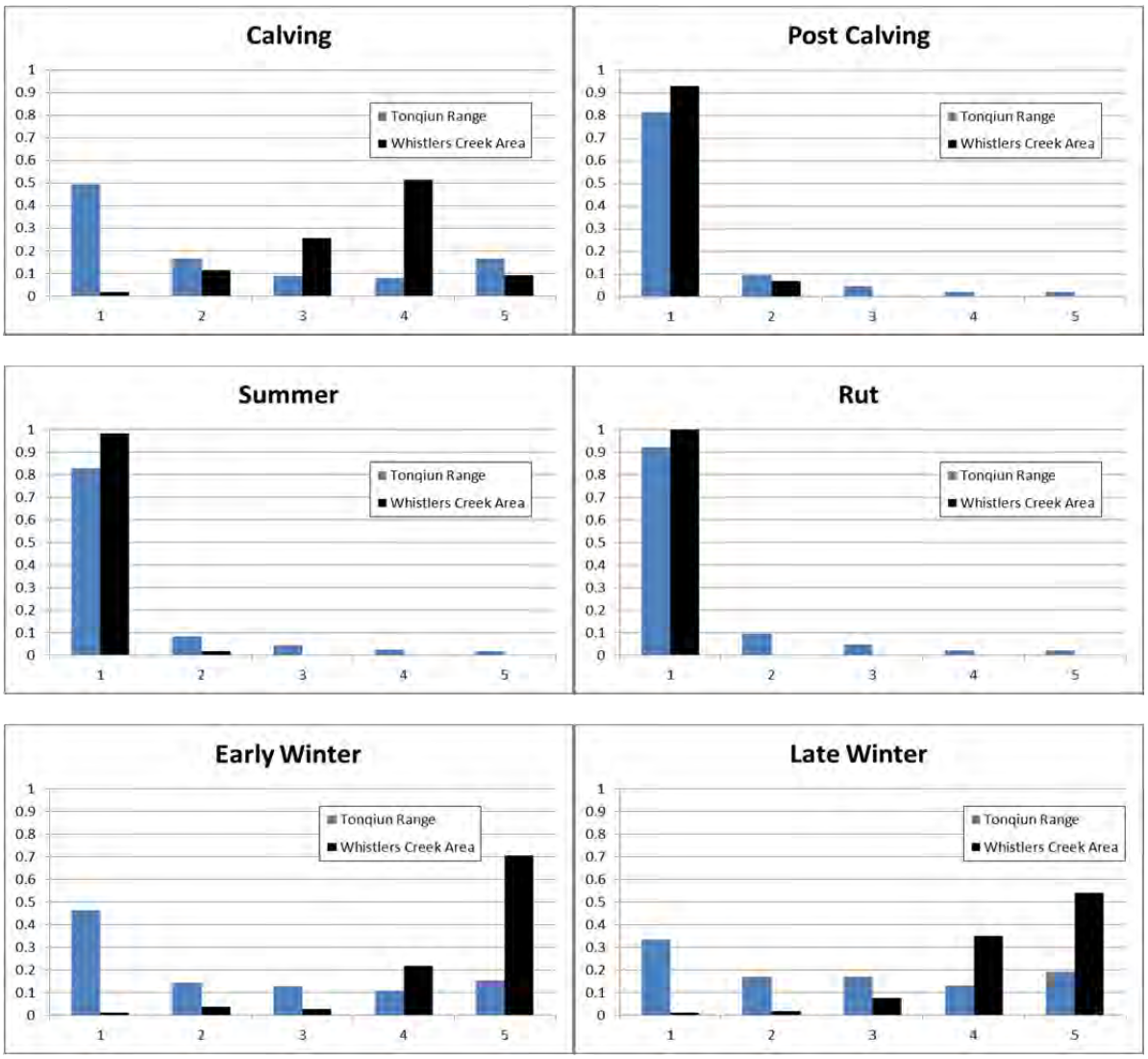


Figure 18. Seasonal distributions of base model habitat values from final RSPF models in the Tonquin Range and the Whistlers Creek area based on caribou locations from 2002-2009. Classes represent assignment of habitat values to equal intervals.



3.2.2 Testing for the Potential Impact of Marmot Basin on Caribou Habitat Selection

Rationale and Methods

We have now quantified and compared the relative 'quality' of seasonal caribou habitat types in all study areas. Here we test whether there is seasonal avoidance of the currently developed area by caribou as a result of human activity. This step is important, because quantifying the potential impact of the area presently developed by Marmot to caribou is key to predicting potential impacts of new developments in the Tres Hombres and Outer Limits areas. Identifying whether Marmot Basin operations affect caribou beyond its boundaries is critical to identifying the actual footprint of the ski area, and whether new developments would significantly increase the present footprint.

To test for a potential avoidance effect, we used seasonal base habitat models and determined whether including a 'distance to Marmot' variable significantly increased model fit. In other words, were caribou avoiding the Marmot Basin Area, after accounting for the seasonal quality of the habitat available in the area? At the range scale, this would be appropriate only if we suspected that Marmot affected animals across the entire range. Specifically, testing the effect of Marmot at distances beyond a reasonable buffer will force the model to fit the greatest proportion of the data, possibly ignoring areas close to Marmot, and resulting in a misleading model. This is depicted in Figure 19, where potential models (colored lines in leftmost box) accurately predict selection (black line in leftmost box) beyond 10 km from Marmot but do not fit data within 5 km of Marmot. Therefore, using data at the range scale for this analysis would have resulted in predicting that caribou selected for areas within 5 km, whereas the data, in fact, show avoidance at this distance.

Winter tourist resorts influenced animal habitat use within a buffer of approximately 10 km (section 1.2) and tourist traffic at Scandinavian resorts was greater than Marmot Basin. Therefore, we postulated that if Marmot basin affected caribou habitat selection, the footprint would be within a 10 km buffer of the resort. As a result, we resampled used and available locations within a 10 km buffer of Marmot Basin and fit models with covariates identified at the Range Scale (section 3.1). We then tested whether the inclusion of the 'distance to Marmot' variable increased model fit based on AIC scores.

Results

The inclusion of the covariate 'distance to Marmot' significantly increased model fit during the calving, summer, and winter seasons (Figure 20). In early winter, the distance to Marmot increased model fit but had a relatively small effect compared to late winter (Difference in AIC score: -12.35). In other words, the distance from Marmot affected selection during these seasons after accounting for the habitat types within the 10 km buffer. During remaining seasons, the inclusion of the distance to Marmot did not significantly increase the predictive ability of base habitat models.

Figure 19. Tonquin caribou selection for distance to Marmot during the calving season (May 23rd to June 20th) using the full final dataset (2002-2009).

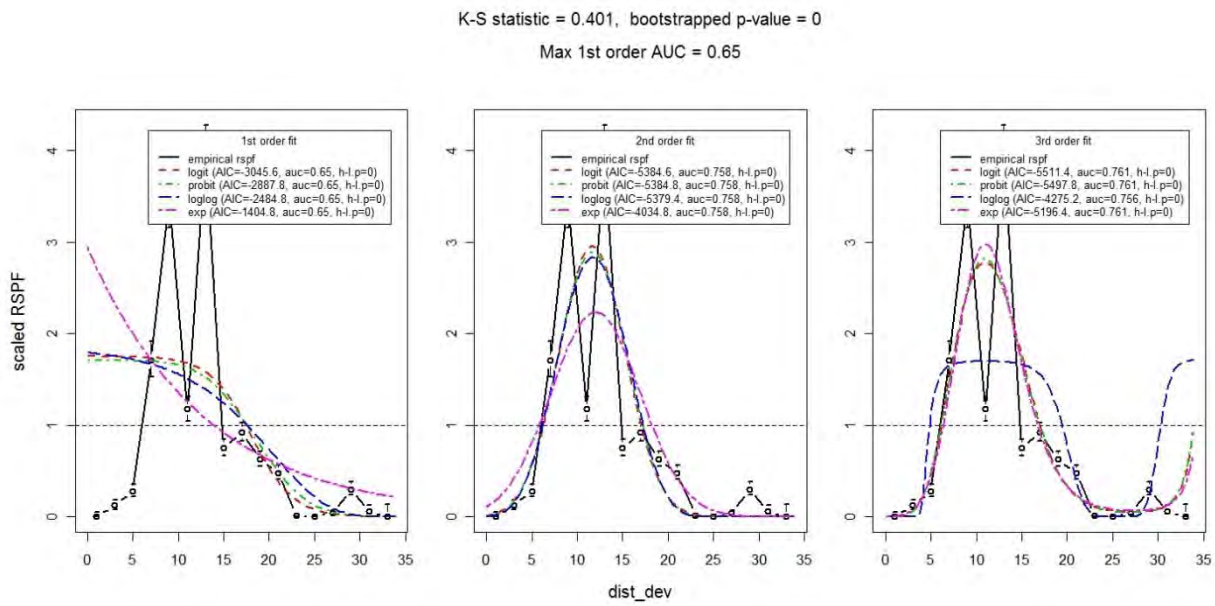
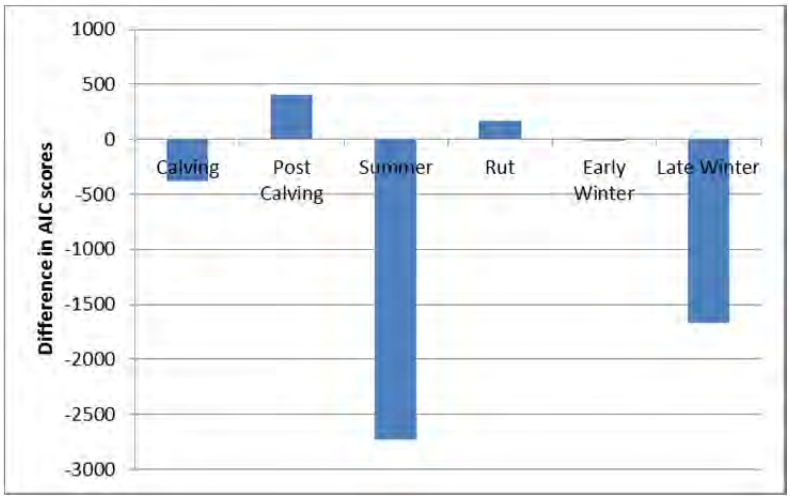


Figure 20. Seasonal difference in AIC scores between base habitat models and addition of the distance to Marmot covariate within 10km of Marmot Basin. Positive values represent a decrease in model fit, whereas negative values represent an increase in fit and thus an influence of proximity to Marmot Basin on habitat use.



3.3 Effect of Seasonal Wolf Predation

3.3.1 Quantifying Wolf Predation Risk in the Tonquin Range

Rationale and Methods

To quantify the seasonal risk of wolf predation within study areas, we first modeled wolf habitat selection at the Tonquin caribou range scale to obtain a sufficiently large sample of wolf location data and combinations of habitat types. We used available collar data from wolf VHF and GPS collars within the boundary of the Tonquin caribou range, and divided the year into winter (3,163 wolf locations, November 1st to May 22nd) and summer (3,609 wolf locations, May 23rd to October 31st) seasons, using the beginning of the caribou calving season and end of the rut as cutoffs.

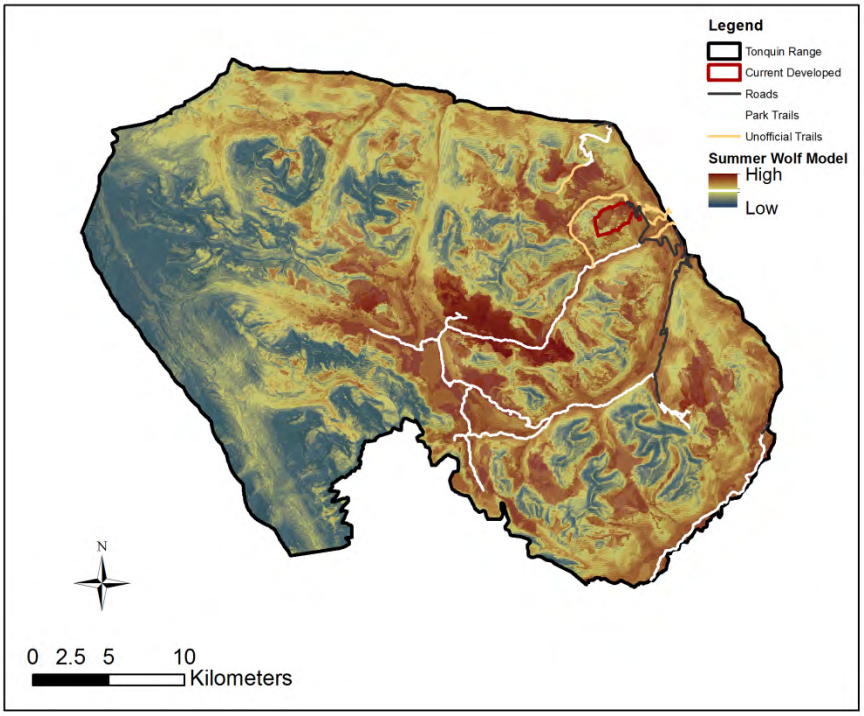
Wolf data used in this analysis represents approximately 20% of available wolf locations for JNP. It is important to note that there have never been dens or long-term resident packs in the Tonquin caribou range. Therefore, the selection patterns presented here describe how wolves use the Tonquin landscape but are not an accurate representation of wolf habitat selection per se. In other words, wolf selection for specific areas of the Tonquin range should be viewed as a secondary selection process after selection for this area within their territory. However, the purpose of this analysis is to spatially describe wolf predation risk when individuals are present in the Tonquin range, regardless of temporal changes in density.

Details of statistical analyses are available in Appendix 6.3; summary results are presented here.

Results

In summer, distance to linear features was the strongest predictor of habitat selection by wolves. Wolves selected primarily for flat alpine areas close to streams and linear features. Secondly, wolves selected for east and south facing slopes of up to 15 degrees (Figure 21). In winter, wolves selected primarily for flat lower subalpine pine habitat at approximately 1500 m. Generally, north-facing slopes were avoided, and selection for other aspects was similar at slopes up to 15 degrees. Selection for areas close to hiking trails was the second most important variable explaining wolf habitat selection after elevation (Figure 22).

Figure 21. Summer (May 23rd to October 31st) wolf locations and habitat selection model for the Tonquin Range 2003-2011.



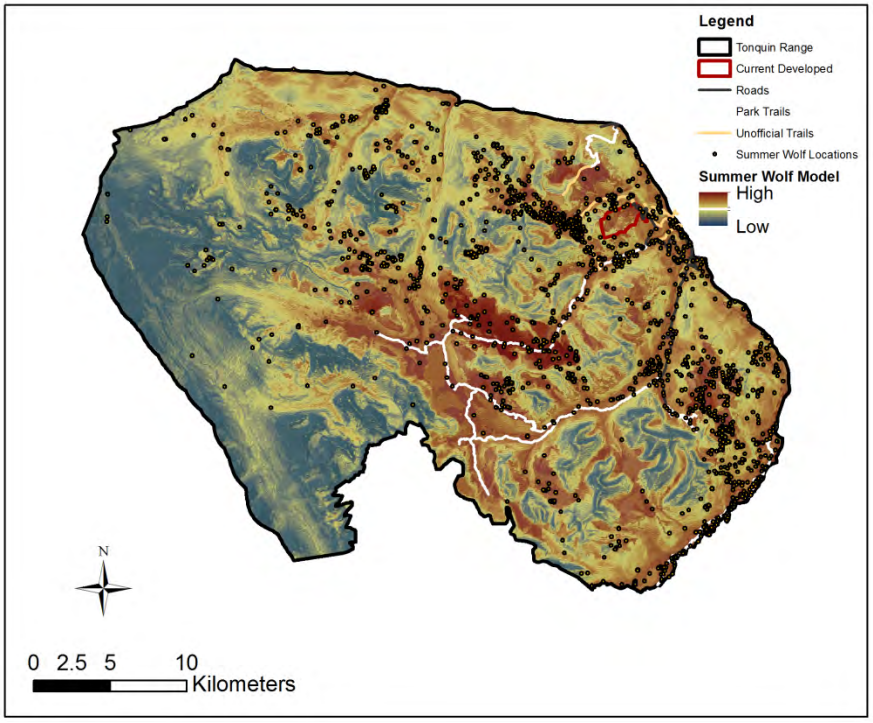
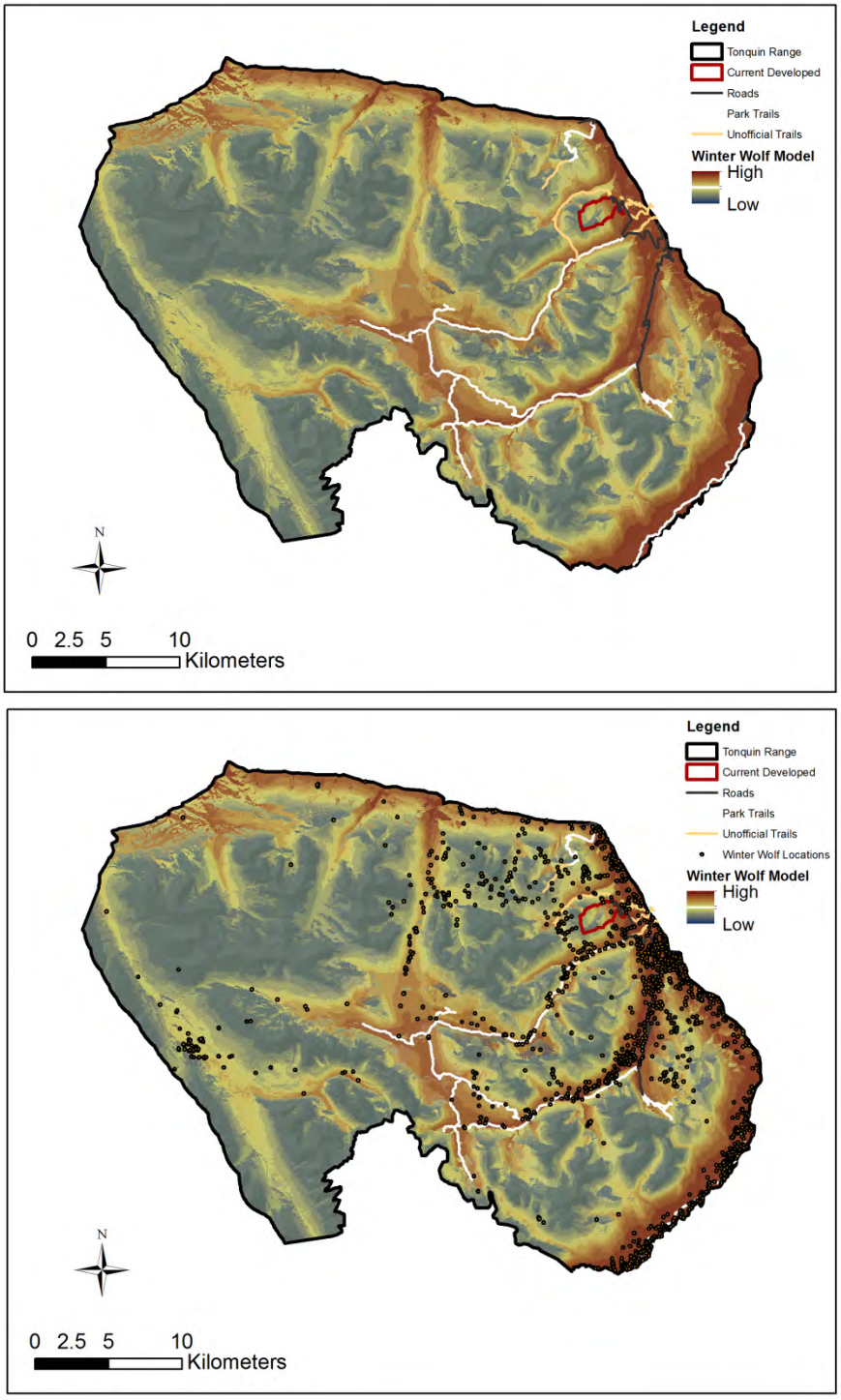


Figure 22. Winter (November 1st to May 22nd) wolf locations and habitat selection model for the Tonquin Range 2003-2011.



3.3.2 Quantifying Predation Risk in Study Areas

Rationale and Methods

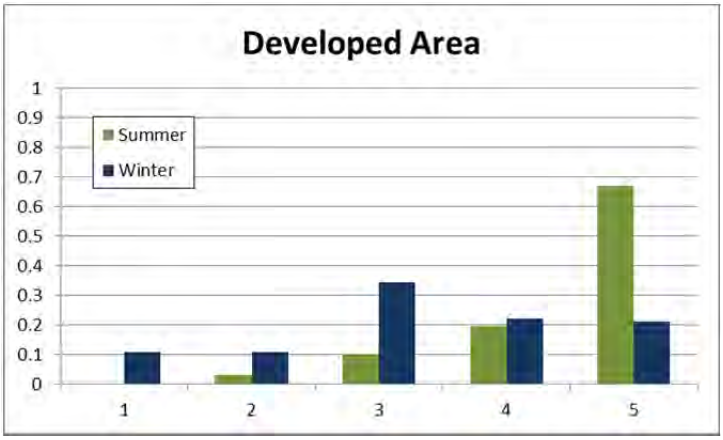
Caribou habitat selection models represent a trade-off between acquiring the necessary resources for survival and avoiding predation risk. The relative importance of these selection pressures can vary by age, sex and season, generating spatial and temporal patterns where caribou are at greater risk. Here, we compare wolf habitat selection values within study areas using selection models generated at the range scale. We extracted study area selection values from an equal area classification of models at the range scale to control for biases in the wolf data (GPS and VHF data) and data quality between seasons.

Results

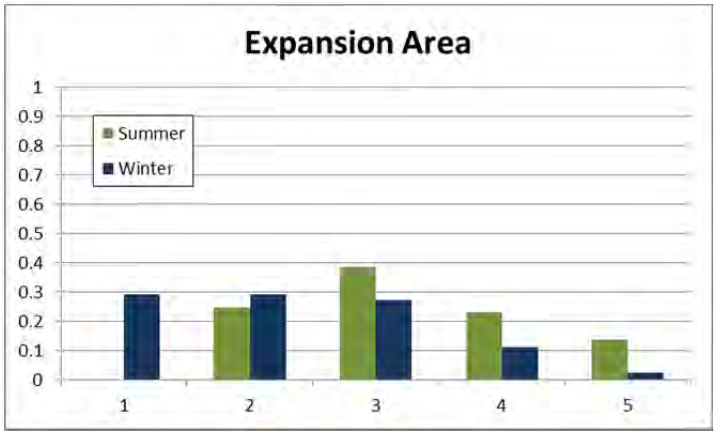
The Marmot developed area contains better than average winter habitat with relatively low predation risk. Conversely, predation risk from wolves was high during the snow-free seasons and at that time does not contain highly selected caribou habitat (Figure 23a). The expansion area does not contain relatively high selected areas by wolves or caribou during the winter seasons but does contain highly selected caribou calving and rutting habitat with low risk of wolf predation (Figure 23b). The Whistlers Creek area contains highly selected caribou habitat with a mid-range risk of predation during the winter seasons. This area also contains highly selected calving and rutting habitat but with greater risk of predation than the expansion area (Figure 23c).

Figure 23. Predation Risk values from final wolf RSPF models in the Tonquin Range based on wolf locations from 2003-2011 in a) the currently developed area, b) the expansion area, and c) the Whistlers Creek area. based on caribou locations from 2002-2009. Classes represent assignment of habitat values to equal area intervals.

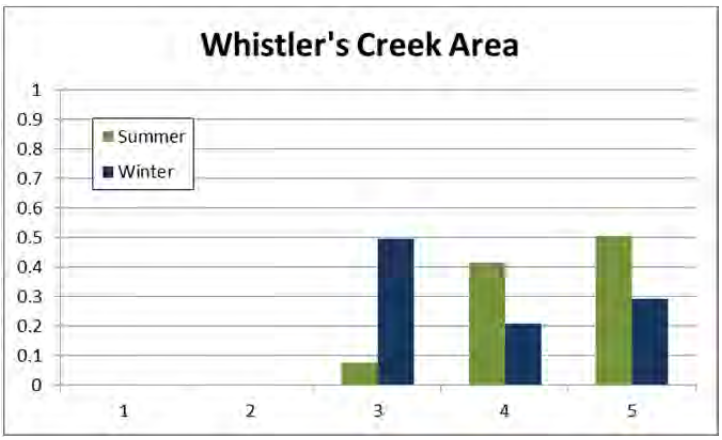
a)



b)



c)



3.4 Marmot Zone of Influence on Winter Habitat Selection

Rationale and Methods

Estimating the zone of influence of Marmot Basin is critical to predicting the footprint of potential future developments in the Tonquin Range. In section 3.2.2, we showed that caribou selection significantly increases with distance from the presently developed area during the calving, summer, and winter seasons (Figure 20). Avoidance of areas around Marmot Basin during the calving and summer seasons could be explained by the relatively high level of predation risk in that area compared to the range (Figure 23). However, predation risk during the winter season was relatively low and does not explain the avoidance. Given the high level of activity at Marmot during the ski season, results suggest that late winter avoidance of Marmot Basin is a result of human activities. Here we estimate the potential functional habitat loss surrounding the area presently developed.

Results

We estimated the minimum zone of influence of Marmot Basin at 2 km in early winter (Figure 24) and 5 km in late winter (Figure 25). Therefore, the footprint of the ski resort and associated infrastructure represents approximately 3% (Figure 26) and 9% (Figure 27) of the absolute area of the Tonquin range, respectfully. Within this buffer, caribou are less likely to select available habitats. The late winter habitat profile of the Marmot area contains preferred habitats in slightly lesser proportion than their distribution over the entire range (Figure 27). As a result, this 9% value should be considered a maximum disturbance estimate with respect to effective loss of habitat. Spatially, the location of Marmot Basin near the northeastern edge of the range results in a lower, predicted disturbance effect than if it were situated more towards the center and had an effect in all directions (Figures 28 and 29). Given its location, the predicted disturbance effect towards the east extends outside the range boundary and was not factored into these estimates.

Figure 24. Visual representation of Tonquin caribou selection for distance to Marmot during the early winter season (November 1st to January 21st) using the full final dataset (2002-2009). The red dashed line represents the logit model fit to the data and the red solid line identifies the estimated distance of avoidance of the developed area in km.

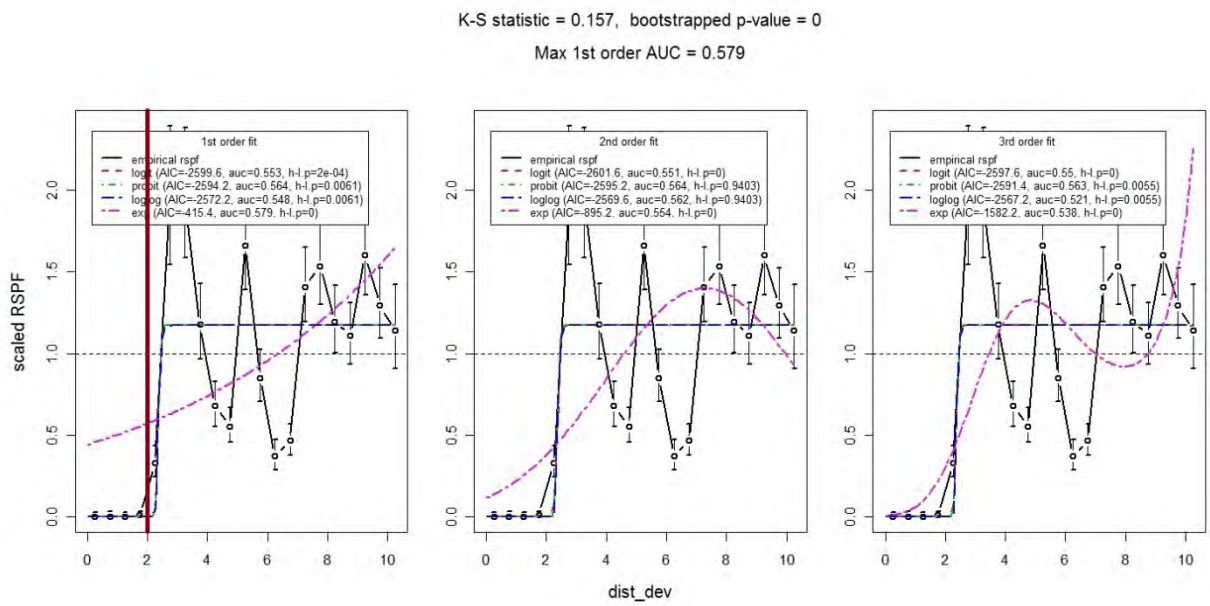


Figure 25. Tonquin caribou selection for distance to Marmot during the late winter season (January 22nd to May 22nd) using the full final dataset (2002-2009). The red dashed line represents the logit model fit to the data and the red solid line identifies the estimated distance of avoidance of the developed area in km.

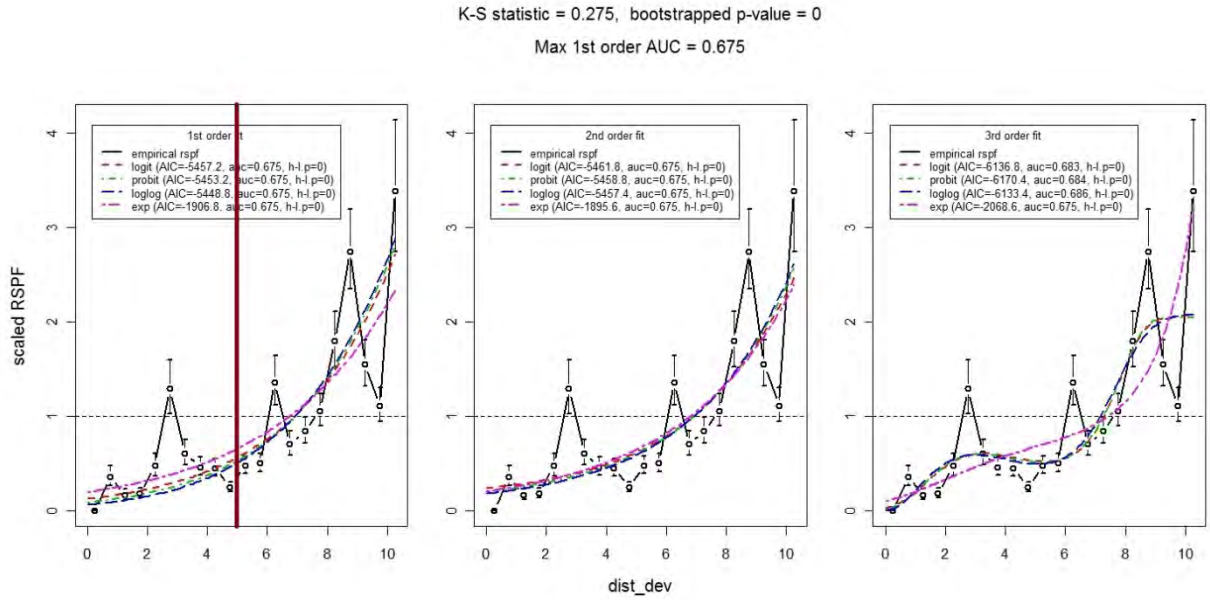


Figure 26. Early winter (November 1st to January 21st) distributions of Tonquin range (blue) and buffer (black) habitat values from final RSPF models based on caribou locations from 2002-2009. Classes represent habitat values assigned to equal intervals. Pie chart values represent the proportion of the range contained within the estimated buffer.

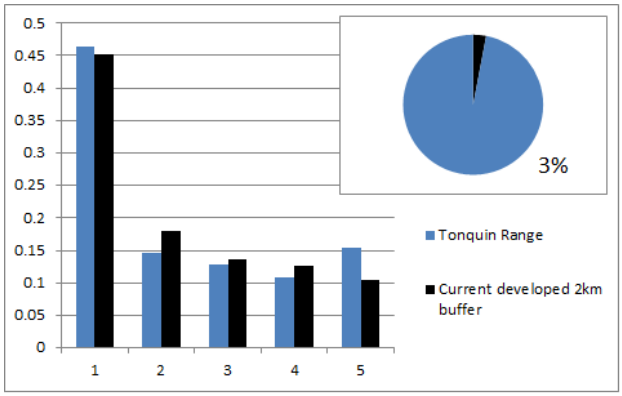


Figure 27. Late winter (January 22nd to May 22nd) distributions of Tonquin range (blue) and buffer (black) habitat values from final RSPF models based on caribou locations from 2002-2009. Classes represent habitat values assigned to equal intervals. Pie chart values represent the proportion of the range contained within the estimated buffer.

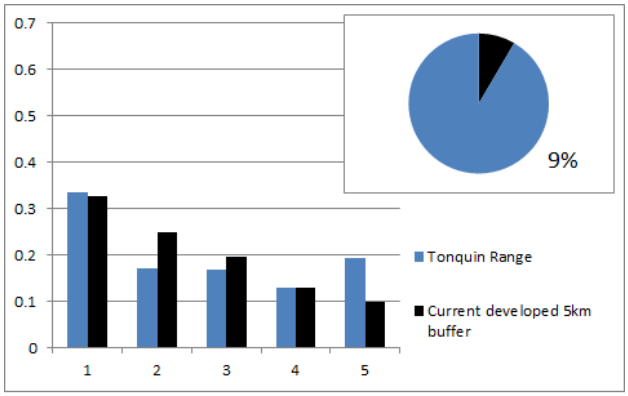


Figure 28. Tonquin caribou selection for distance to Marmot during the early winter season (November 1st to January 21st) using the full final dataset (2002-2009).

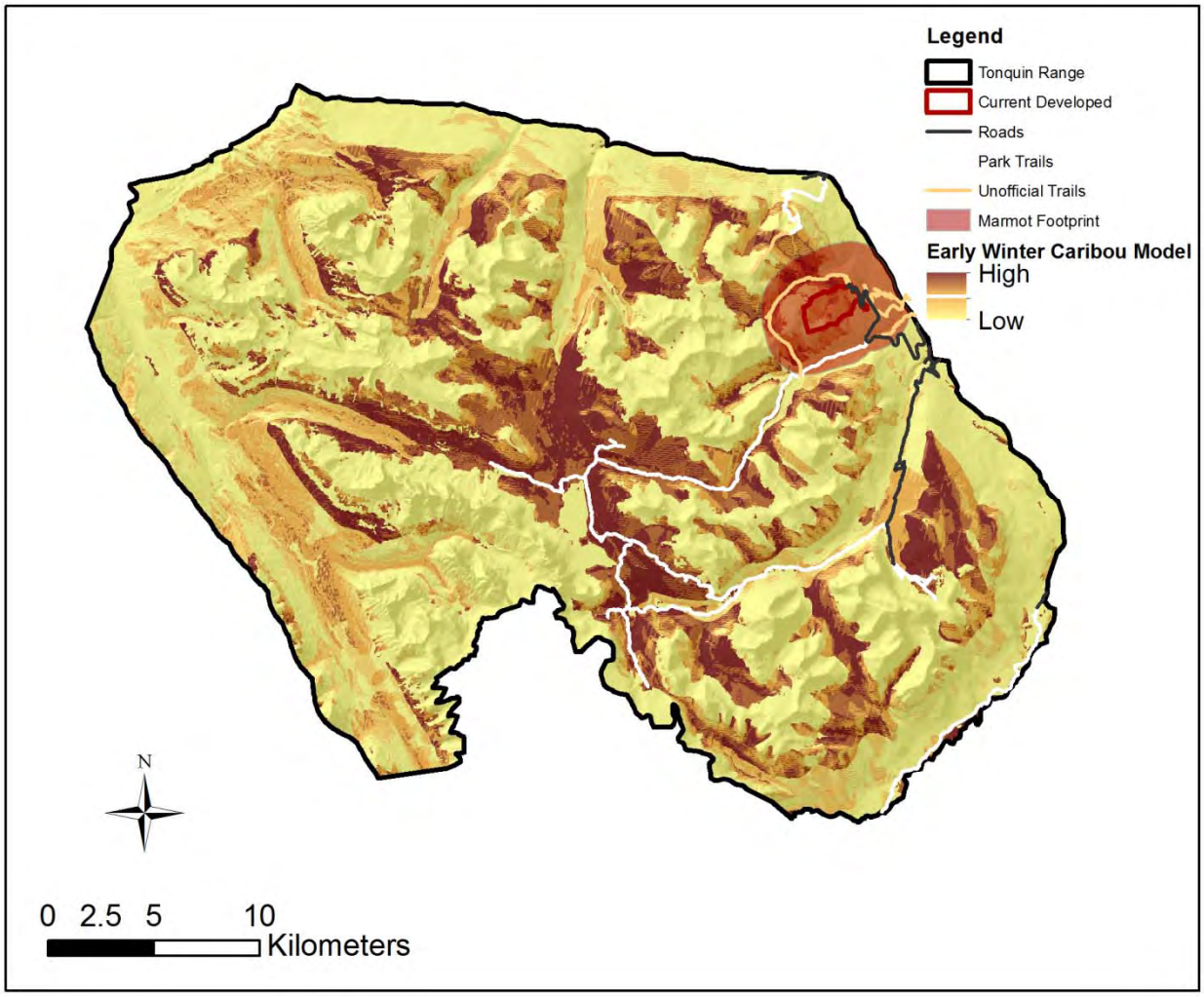
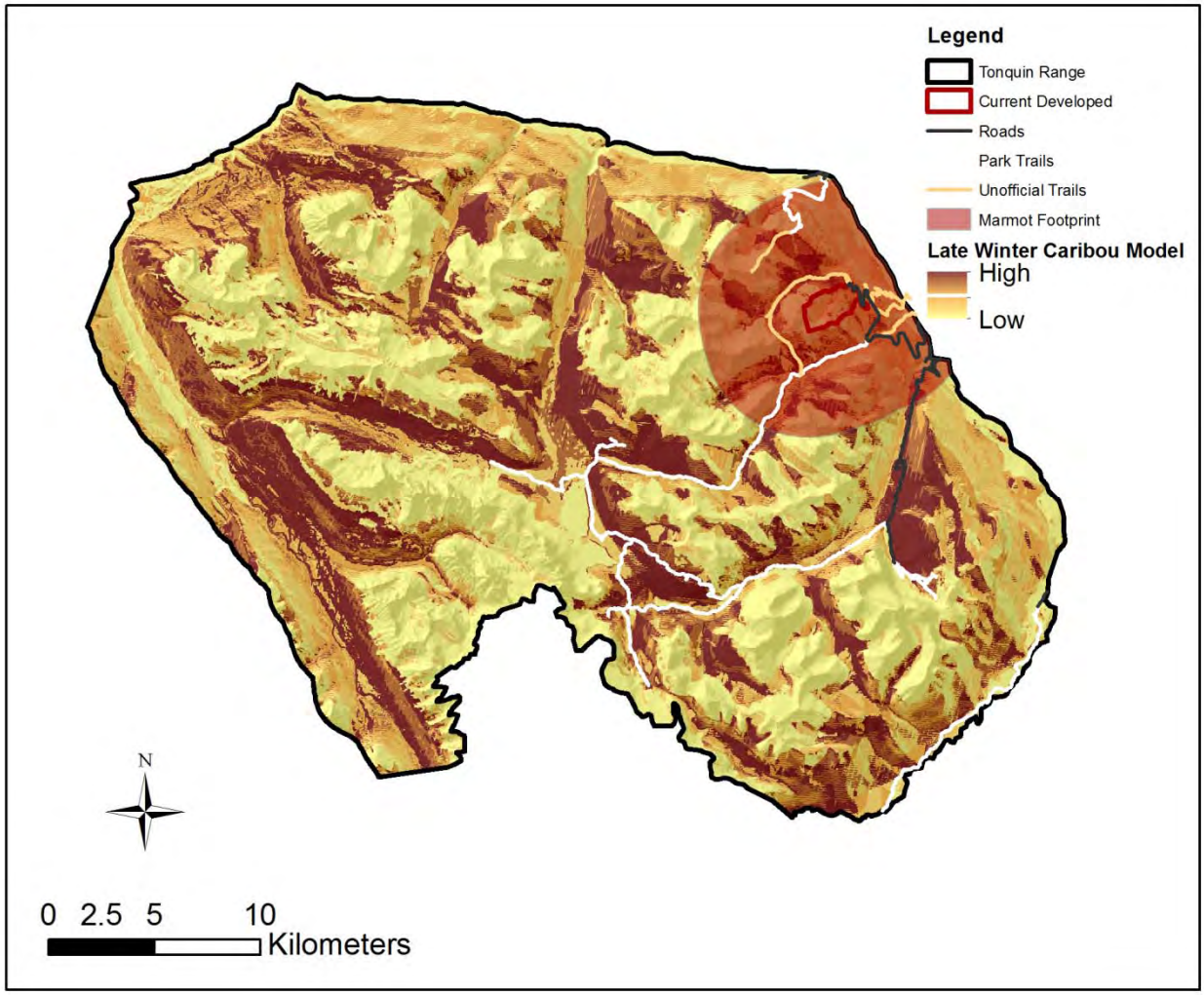


Figure 29. Tonquin caribou selection for distance to Marmot during the late winter season (January 22nd to May 22nd) using the full final dataset (2002-2009).



3.6 Implications of Potential Developments in the Tonquin Range to Caribou Population Viability

Rationale and Methods

There is yet no comprehensive meta-analysis of range disturbance thresholds for mountain caribou populations on which to base an assessment of present and proposed cumulative effects to Tonquin Caribou population viability. This knowledge gap is identified as a required study to complete the identification of critical habitat for southern mountain caribou (Environment Canada 2014). Given the importance of establishing some context for the level of development within the Tonquin range, we use estimated disturbance in the Tonquin range and information from boreal caribou to provide an interim assessment of the range and Tonquin caribou probability of persistence. Specifically, we rely on thresholds and criteria established by multiple studies in the "Scientific Review for the Identification of Critical Habitat for Woodland Caribou, Boreal Population, in Canada" (2008), and the 2011 Update herein referred to as the Scientific Reviews.

This approach is consistent with the recent Recovery Strategy for the Woodland Caribou, Southern Population, where the boreal analysis also was used to establish an initial reference until such time that specific information is available for southern mountain caribou (Environment Canada 2014). The 2011 assessment extends the 2008 approach and addresses several key areas of uncertainty in the earlier assessment. However, it does not represent a fundamental shift from the premise that range is the appropriate geographic delineation. Further, the amount of total disturbance within a range remains a key criteria for identifying critical habitat to meet a goal of self-sustaining local populations of caribou. The Scientific Reviews provide the best available scientifically-based criteria to assess the population viability of the Tonquin population and inform discussions relevant to anthropogenic developments and disturbance levels within the range.

The Scientific Reviews define "risk" as the likelihood that a range can maintain a self-sustaining local population, and provides a measure of uncertainty surrounding the indicators used in the assessment. The Integrated Risk Assessment has 2 main components:

1. A statement about the probability that current range conditions, described in terms of habitat and population conditions, are sufficient to support a self-sustaining population.

2. The uncertainty in the Integrated Risk Assessment was assessed using two measures: a statement of certainty that reflects the type of information used to estimate the indicators of self-sustainability, and the consistency in these indicators.

We use data from annual caribou progress reports and updated population estimates provided by JNP to assess population condition. We assess habitat condition based on the degree of anthropogenic

disturbance in the range and the extent of fires having occurred within 50 years. The Scientific Reviews showed that a general buffer width of 500 m for all anthropogenic disturbances provided an appropriate, minimum approximation of the zone of influence of these features on caribou demography. Recognizing the limitations of comparing disturbance levels in boreal and mountain caribou ranges, here we generate several estimates of disturbance in the Tonquin range using variable decision rules.

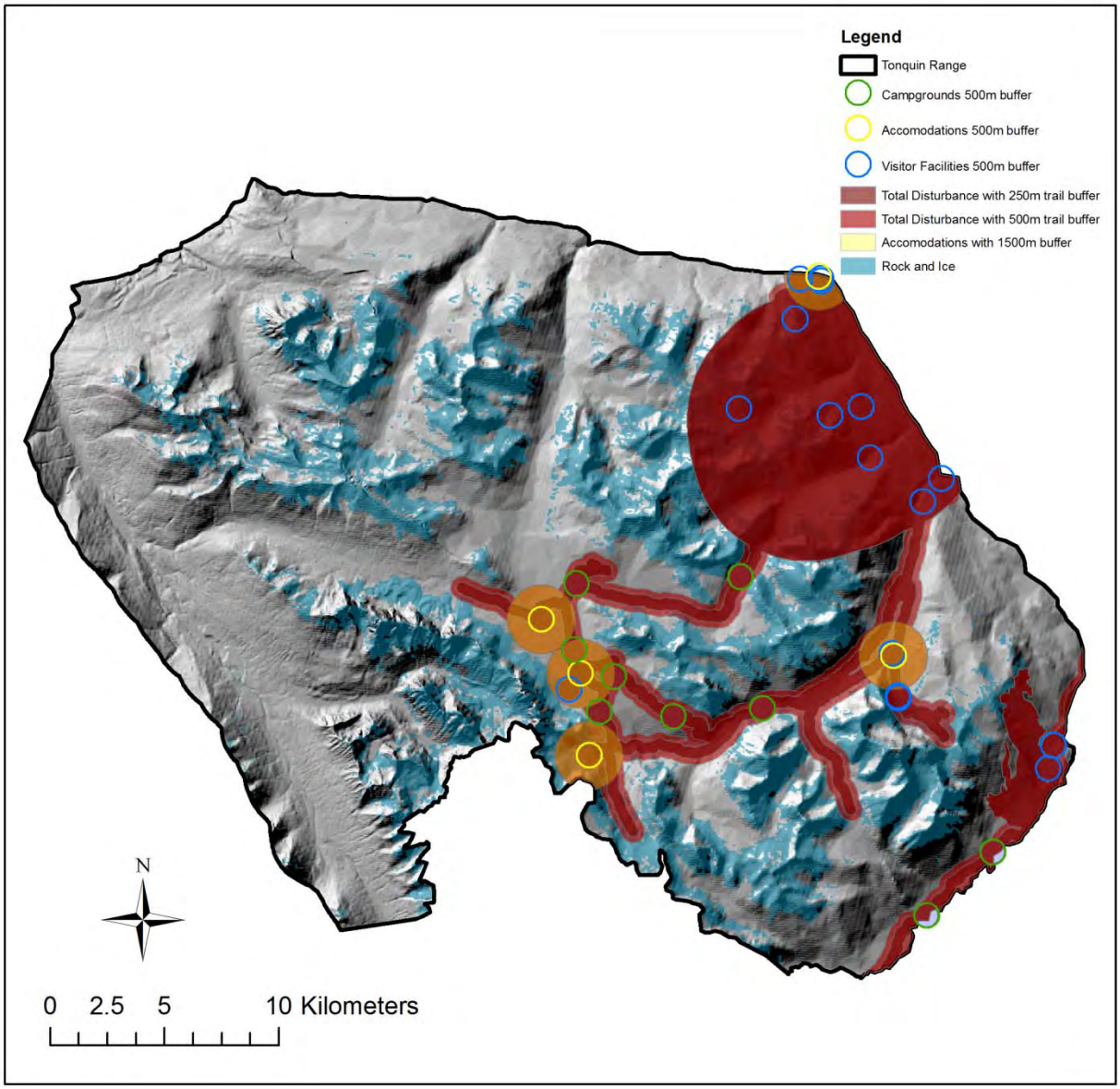
First, we used the Scientific Review method evaluating effects on caribou demography, whereby all anthropogenic disturbances were buffered by 500 m and merged with fires having occurred within 50 years. Second, we estimated source specific buffer distances based on the best available information on caribou avoidance. Specifically, we buffered popular Park hiking trails by 250 m based on caribou avoidance of seismic lines and pipelines (Dyer et al. 2001) and used a buffer of 1.5 km around accommodations based on the estimated zone of influence of hunting cabins on caribou (Polfus et al. 2011). Although complete human-use information is not available, these locations contain permanent lodging structures and are used year-round to various degrees and this distance falls within the 0-5 km critical tolerance distance to human infrastructure independent of human activity (Nellemann et al. 2000). We assumed that disturbance around campgrounds (used by small groups) and tourist facilities was intermediate and assigned a buffer of 500 m. Thirdly, for both general and fine buffer distance estimations, we next removed areas of rock and ice from the approximation of range size to estimate the total area disturbed as a function of habitable area in the range thus reducing some bias associated with comparing boreal and mountain caribou ranges.

Results

We estimated that present disturbance for Tonquin caribou ranged between 16% and 22% depending on buffer distances and whether non-habitable areas of the range were used in the calculation of range size. These results are consistent with the Scientific Reviews that found little statistical support for decomposing disturbances into more specific classes. Based on this habitat assessment, current range conditions are *likely* to maintain a self-sustaining population over time. However, this habitat-based indicator of population growth was not consistent with the available demographic information on population size and trend. Specifically, annual population estimates show a decline since 2006 from 111 (92-186) to 54 (45-82) in 2011 and the population assessment component of Critical Habitat identification recognized that very small populations (<50) are vulnerable to stochastic events and phenomena, resulting in an especially low probability of persistence. The population decline is particularly sharp in females, from 58 (±8) in 2006 to 21(±0.0005) in 2011, and the number of mature females would comprise an even smaller portion of these estimates. These recent results are near the minimum thresholds for quasi-extinction (10 reproductively active females) and as such serve as an additional indicator of additive risk of extinction due to small population size (N=54).

Recognizing the uncertainties in using boreal range disturbance criteria to evaluate mountain caribou persistence compared to the high level of certainty associated with the available demographic data, we apply the Scientific Reviews decision rules established for weighting the individual criteria as part of an integrated assessment. Consequently, we find that there is *considerable evidence* to categorize the Tonquin caribou range as *not self-sustaining*. This evaluation is consistent with the Scientific Review recommendation to base the evaluation on the indicator that produced the highest risk or lowest probability of meeting the goal of maintaining a self-sustaining population and to adjust the integrated risk assessment to indicate cases where there might be an increased risk of extinction due to small population size. Furthermore, this evaluation also is consistent with the 'Very High' Cumulative Effects Threat Assessment for the Central Group of southern mountain caribou as calculated by the IUCN Threat Calculator (Environment Canada 2014).

Figure 30. Total disturbance (fires within 50 years and anthropogenic) and habitable areas in the Tonquin range. Total disturbance includes a 5 km around Marmot Basin.



4.0 DISCUSSION

Landscape Scale Tonquin Caribou Habitat Selection Patterns

Overall, locations from collared female caribou were distributed throughout the entire Tonquin range within each season, thus providing reasonable spatial representation of selection patterns. Despite observed differences between individual caribou, we believe that final seasonal models represent accurate characterizations of seasonal behaviors for female caribou. Robustness was integrated through rigid covariate screening before potential inclusion in final models. Although different models best predicted selection in each season, model differences were greatest between the winter and non-winter seasons. During the latter, snow-free seasons, caribou generally selected for alpine patches and avoided other habitat types, whereas several habitat types were selected during the winter seasons. In addition to a greater diversity in selection of habitat types in winter compared to other seasons, variability between individuals also was more pronounced during winter. In other studies, greater variability in selection during winter months has been attributed to spatial and temporal variation in snowfall (Wittmer et al. 2006).

During the snow-free period, individual selection patterns were remarkably similar. Unfortunately, Tonquin caribou collar data consist of locations of 1-4 individuals per year over 8 years, making it challenging to identify trends. However, during these seasons, the observed individual variation appeared correlated to the spatial distribution of caribou locations. Specifically, during the non-winter seasons, animals with overlapping seasonal locations exhibited similar inter-annual selection patterns, suggesting that permanent local landscape features were driving individual differences in selection.

During the summer and rutting seasons, models suggest that caribou significantly select for areas near linear features. This modeling parameter is misleading, however, because it is unlikely that animals are attracted to the features per se, but they do select for alpine patches, through which there happen to be hiking trails. Specifically, caribou locations during these seasons are concentrated near the main Tonquin Valley hiking trail and its bisecting trails (Moat Lake, Maccarib Lookout). Therefore, although a predictor of Tonquin caribou locations on the landscape in this study, the association of caribou and trails should not be interpreted as caribou actively selecting for areas near linear features.

Caribou Selection of Study Areas

The specific areas that were the focus of this study occupy a small proportion of the Tonquin caribou range. Quantifying the seasonal value or quality of these areas with respect to the range provides a more accurate assessment of the anthropogenic footprint of associated infrastructure and activities. In particular, if seasonal habitat in a study area is of disproportionately greater value than, on average, the range, then the loss of the area would be greater than represented by its actual size. In describing the

quality of seasonal habitats in study areas, we assumed that areas of high probability of selection were biologically important and therefore identified high quality habitat (Railsback et al. 2003).

The predicted value of seasonal caribou habitat in the currently developed area was greater than the mean habitat quality in the range in most seasons. In winter, this is a result of the large proportion of highly selected upper subalpine habitat identified in the area. In reality, the value of this subalpine area has been significantly reduced as a result of multiple transecting ski trails. As such, the relatively high quality attributed to this area in winter represents the value of the Marmot Basin lease prior to development. This is consistent with observations of caribou inhabiting Marmot Basin's cirque in summer and ridges in winter before ski area development (Leeson 1986).

The Whistlers Creek area also contained high quality early and late winter habitat of disproportionately greater value than available over the range. However, unlike the developed area, it is comprised mostly of undisturbed upper subalpine forest. Presently, only the unofficial Whistlers Creek trail transects the length of the area; therefore, the quality of caribou habitat in the area should be evaluated based on the level of human and predator traffic on the trail which could vary between years and seasons. This trail will be outside the lease area when the new leasehold boundary comes into effect and thus be managed by Parks Canada. Consequently, motorized vehicle access will be restricted under the National Park Wilderness Declaration Regulations. The area also contains a mineral lick well used by goats (JNP pers. com.), but its value as a resource to Tonquin caribou is unknown. Observations of barren ground caribou concentrating around mineral licks suggest that the resource could provide important mineral elements lacking in their diet (Heard and Williams 1990); however, these features have not been identified as critical habitat for southern mountain caribou (Environment Canada 2014).

Generally, the expansion area contains a similar distribution of caribou habitat quality to its availability in the range in all seasons, owing in part to a large portion being described as rock/ice and steep slopes. The only noticeable deviation is a greater distribution of mid-level quality habitat during the calving season, and a lower than average distribution of highest quality habitat in late winter.

Despite there being better than average seasonal caribou habitat in the study areas based on selection patterns across the range; none of the collared female caribou used any of these areas in any season. Collared caribou were within a reasonable travel distance of Marmot Basin in all seasons, and there were no obvious biophysical constraints on movement. For example, one collared female caribou spent time in an alpine patch located approximately 2 km from the expansion area during the rutting season. Therefore, distance or physical barriers could not explain the lack of GPS collar locations in the Marmot Basin area. We recognize that GPS collar data do not represent the entirety of caribou use, and observation data indicate that caribou do use this valley, but contemporary sightings are not regular or common (JNP pers. com.). This contradicts earlier reports of caribou being "commonly observed" in the Whistlers Creek drainage (JNP Warden Service Report 1984) when the population contained more individuals and fewer skiers used the area. The majority of recent caribou sightings in the study area are

believed to be males (Marmot Basin Staff pers. com.), the segment of the population most tolerant to disturbance (Smith and Cameron 1983, Helle and Sarkela 1993, Nellemann et al. 2000).

Potential influence of skier and other visitor use on caribou use of habitat in and around the Whistlers Creek drainage

New ski area development in the Tres Hombres and Outer Limits areas could significantly increase the number of people in the vicinity of the Whistlers Creek area (Figure 2), which in turn would be expected to increase the risk of encounters of caribou in the area with visitors. However, increased levels of activity could also result in further reductions in the likelihood of caribou in the area. Generally, caribou avoidance is related to level of activity (Bradshaw et al. 1997); therefore, higher skier volume within a restricted area of the range would likely increase avoidance of the area and therefore not necessarily result in an increased number of direct encounters between skiers and caribou. Increased avoidance and alienation of additional portions of the range is not, however, a desirable outcome. Recently, Ski Marmot Basin has advanced for consideration an option that entails restricted chairlift access on the upper scree slopes of Outer Limits and Tres Hombres. This option would restrict human use in the treed portions of Whistlers Creek and is likely to result in a lower probability of skiers encountering caribou. This proposed modification represents a reduction in footprint compared to the initial proposed development; however, this development would still result in additional disturbance in an area that is currently rarely used by skiers. In addition, it may be difficult to restrict off-site skiing into Whistlers Creek.

For more disturbance-tolerant ungulates such as moose, using areas with increased human activity can reduce wolf predation pressure (Kunkel and Pletscher 2000). However, caribou appear to generally avoid the Marmot Basin area and, in Norway, reindeer showed no indication of habituation to 10 alpine resorts during a 20 year period (Nellemann et al. 2010). Therefore, although mitigation measures should be established to reduce stress to more tolerant individual caribou using areas near Marmot, it is unlikely that mitigation in the expansion area would significantly change the existing footprint of the Marmot Basin Ski Area, and therefore the overall level of use of the general Marmot Basin Area while it is operating as a ski resort. However, the relative importance of mitigation focused on more tolerant individual caribou should be evaluated within the current context of Tonquin caribou population size and trend.

Our results show that Tonquin caribou winter habitat selection, predominantly during the late winter, has already been reduced within a buffer of approximately 5 km of the presently developed area. This avoidance cannot be explained by predation risk, suggesting that late winter avoidance of Marmot Basin is a result of human activities. As such, an increase in activity in the expansion area may further reduce caribou occurrence in the vicinity but may not result in an avoidance effect greater than that already detected. Similarly, research in Scandinavia showed that it is the first construction in an area that has

the greatest impact on caribou distribution (Vistnes and Nellemann 2001). However, the entire Tonquin range may be considered high-elevation critical habitat and any new activity resulting in displacement of caribou from part of their range is considered destruction of critical habitat (Environment Canada 2014). Given the declining population trend and increased risk of local extinction associated with the most recent estimate of population size, additional anthropogenic disturbance within the range could exacerbate current conditions, and is not consistent with population recovery objectives. In addition, recovery activities should include mitigation to reduce current disturbance in the Tonquin range.

Potential influence of anthropogenic disturbances on predation risk

Predation is the most important proximate factor in the decline of caribou populations in Jasper and Banff National Parks, and therefore the focus of conservation efforts (Bradley and Neufeld 2012). Wolf numbers in Jasper have generally mirrored population trends of elk, their primary prey (Bradley and Neufeld 2012). However, predator control programs in the early years of elk introductions, and the dumping of road-killed elk in gravel pits until 2006, probably contributed to artificially high predator numbers and predation risk to caribou (Bradley and Neufeld 2012). Present management and research goals are to remove “unnatural” human impacts, to reduce elk mediated apparent competition now that elk abundance is low, and to monitor transitioning predator/prey dynamics (Bradley and Neufeld 2012). In the Tonquin range, these impacts include linear features that can increase predator efficiency thereby increasing predation pressure (Thurber and Peterson 1994). As such, trail closures have been identified as a top priority for the Park (Bradley and Neufeld 2012).

Evidence suggests that, at present, the anthropogenic disturbance with the greatest spatial overlap with Tonquin caribou is trail access into prime summer range, most of which is located outside the Marmot Basin area. During the snow free seasons and particularly in summer, Tonquin caribou concentrate in large patches of alpine habitat, most of which are located in the central and south-eastern parts of the range. Almost all areas predicted to be of highest quality are accessible by Park hiking trails, particularly the largest alpine patches in the center of the range (Figure 12).

In summer, we found linear features to be the strongest predictor of wolf habitat selection in the Tonquin range, followed by alpine habitat. This relationship does not necessarily imply that wolves are selecting specifically for trails/roads, but that when they are in the Tonquin range they select for areas that happen to be related to roads and trails. Selection for elevation was bimodal for valley bottoms and higher elevation alpine areas and did not account for as much variation in wolf selection patterns as distance to trails/roads. The strength of this association is a result of the large number of wolf locations on/near roads and trails in the eastern portion of the range and in several alpine patches associated with these trails. In fact, wolves selected for areas within 2.5 km of trails/roads (Figure 133), which suggests that wolves are selecting for landscape features associated with trail/road placement at low and high elevation, possibly because of their attributes as corridors.

This summer wolf selection pattern overlaps greatly with caribou selection of Tonquin valley alpine areas and associated trails, suggesting high predation risk in the center of the range. However, actual wolf use is greatest in the eastern portion of the Tonquin Range. In addition, there are few caribou mortalities during the summer season (JNP data); however, this overlap between wolves and caribou is indicative of the potential for high predation risk to a large proportion of the population should wolf density and/or use increase in the Tonquin range.

Wolves also selected for trails and roads in winter; however, caribou were less selective of specific habitat types and also were spatially more distributed across their range. In particular, caribou were more likely to use the eastern part of the range where the likelihood of encountering wolves is greater. This seasonal expansion in the spatial distribution of Tonquin caribou could explain the general pattern of increased wolf-caused mortalities in late winter. The observed vulnerability of caribou to predation in late winter and spring, the close association of wolves with roads and trails found in this study, and the declining trend of the Tonquin population reinforce that *any* mitigation measures that could reduce predator efficiency should be a priority. Mitigation to reduce predation rates would likely have the greatest immediate population level impact for caribou population viability. Given the declining trend and low probability of persistence under current conditions, we recommend that mitigation measures that influence snow compaction and predator efficiency in the Tonquin range be implemented.

Ecological thresholds and implications of potential development and human use in the Whistlers creek drainage to regional population viability

Tonquin caribou population and range disturbance estimates provide *considerable evidence* that the Tonquin caribou range is presently *not self-sustaining*. This evaluation is based on the most current population estimates available for this assessment, and because of the recent population decline, is not consistent with other population viability analyses that include this range (Hebblewhite et al. 2007, Decesare et al. 2011). Inconsistency between disturbance and population indicators could be a consequence of applying estimated boreal caribou disturbance thresholds to mountain caribou, which exhibit differences in range use (Reid et al. 2013). However, it should also be noted that the boreal caribou disturbance assessment was based on a probabilistic approach using multiple criteria, and the present evaluation is generally consistent with for boreal caribou populations with similar population indicators. Specifically, 14 of the 57 ranges evaluated as part of that review had populations below 100 individuals, and 11 (79%) had integrated risk assessments concluding that the ranges were either unlikely or very unlikely to support self-sustaining populations over time. The Tonquin caribou population is also classified as not self-sustaining as per criteria established for southern mountain caribou (negative population growth and population below 100 individuals, Environment Canada 2014).

The current total disturbance, estimated at 16-22%, is a snapshot that will likely change over time depending on environmental conditions and management decisions. The present total disturbance in

the range was almost equally divided between the calculated footprint of the currently developed area of Marmot and the buffered Park hiking trails and associated infrastructure, with very little of the range affected by fires in the past 50 years. These disturbances operate differently on the landscape, and although their spatial footprint offers insight into their present contribution to total disturbance, their relative temporal predictability and potential for mitigation should be considered in future long-term strategic planning.

There are significant challenges in determining whether reduced selection for habitats within the 5 km buffer is resulting in sustained population level effects. In Scandinavia, female caribou forced into suboptimal habitats or overgrazed areas in late winter resulted in reduced female condition, and food limitation can result in lowered reproductive success (Skogland 1984, Eloranta and Nieminen 1986, Nellemann et al. 2003). While such effects are unlikely in the Tonquin range at present population levels, these concerns may be relevant if a management objective is to restore the caribou population to pre-1970s numbers.

Although the assessment of potential implications of Park trails and other infrastructure to caribou population viability was beyond the original scope of this risk assessment, the inclusion of all anthropogenic disturbances was necessary to estimate total range disturbance based on criteria from the Scientific Reviews. This analysis also provided perspective on the relative contribution of potential developments in Whistlers Creek to Tonquin caribou population viability. Specifically, whereas the effects of the Marmot ski area appear mostly restricted to winter habitat loss and reduced habitat use, trail and road access contribute to both total range disturbance and increasing predation risk. Therefore, potential development and human use in the development area and the potential new ski lift should be viewed as the second most important contribution to population viability after the disturbance and predation risk associated with roads and trails.

Lastly, although at present a small contribution to total disturbance, the proportion of the range disturbed by fire should be considered temporally unpredictable and mitigation options will depend on fire origins (i.e. natural versus prescribed). Caribou avoid burned areas during all seasons (Robinson et al. 2012), and only begin selecting for these areas 75 years post-fire (Shepherd et al. 2007). Therefore, the direct effect of fires can play an important role in population viability, while its indirect influence will depend on its size and location (Robinson et al. 2012). Specifically, fires within areas highly selected by caribou can increase caribou/wolf overlap and affect predation risk (Robinson et al. 2012). Therefore, in terms of mitigation, prescribed fires within the Tonquin range should be conducted so as to limit potential indirect negative effects to caribou (Robinson et al. 2012), and the option for fire exclusion in caribou range for short-term habitat protection should be evaluated (Shepherd et al. 2007). The unpredictable nature of natural fires limits our ability to make predictions within a relatively small area such as the Tonquin range. A single high-severity fire could significantly change the total disturbance estimate for the Tonquin range. Therefore, should a large fire occur, mitigation options, priorities, and population status would have to be re-evaluated based on new conditions.

The Tonquin population is the largest in South Jasper and as such can be considered vital to regional population viability. Trends for most surrounding mountain and boreal caribou populations are declining. Achieving self-sustaining populations in surrounding areas with high levels of industrial development and multiple stakeholders will be challenging. Recovery actions for caribou populations with ranges within Park boundaries are urgent and can inform and potentially influence the outcome of management decisions for surrounding populations. The recent decline in Tonquin caribou numbers to a critical level, the result of the threat assessment for the regional caribou (the central mountain group) as very high (Environment Canada 2014), and Parks Canada's mandate to maintain ecological integrity emphasizes the need to implement all possible mitigations to reduce threats to critical habitat, reverse the declining population trend, and work towards the recovery goal of achieving self-sustaining populations in all local populations (Environment Canada 2014).

5.0 RECOMMENDED MITIGATION AND SUGGESTED FUTURE RESEARCH

This assessment concludes that additional anthropogenic disturbance within the Tonquin caribou range could exacerbate conditions that are currently contributing to a declining population and result in destruction of potential critical habitat, and is therefore not consistent with population recovery objectives to achieve self-sustaining status (positive and/or stable population growth and at least 100 individuals, as per the proposed Southern Mountain Caribou Strategy). We nevertheless provide general guidelines and recommendations for mitigation of potential future development as a starting-point from which Marmot Basin and Parks Canada staff can establish specific mitigation measures that can be reasonably operationalized , should development be considered. Suggested future research identifies information gaps we consider important to further asses the current conditions, more accurately evaluate the potential impacts of future expansions of ski areas and hiking trails, and improve understanding of potential mitigation measures.

5.1 Recommended Mitigation

- **Evaluate future potential development in the Tonquin range based on its contribution to the total disturbance footprint.** We recommend any future developments be evaluated based on their estimated level of disturbance, its spatial location, and the assessed quality or 'value' of caribou habitat in the area. Specifically, new developments should be located as close as possible to the center of the current area developed by Marmot Basin to avoid increasing the total disturbance footprint. Similarly, potential future trail development should be restricted to general areas where trails already exist. As such, trail extensions into presently inaccessible areas and areas of seasonal importance to caribou should be avoided. We note, however, that current trails are likely contributing to the observed population decline, thus an overarching recommendation is to reduce overall trail access and use within the range.

- **Avoid expansion area during calving and rutting.** The expansion area contained a greater proportion of higher quality calving and rutting habitat than the average across the range. If chairlift and/or other infrastructure construction were to occur, work should begin after the end of the calving season, during which female caribou are particularly sensitive to disturbance.

- **Examine egress route**. The present egress route used by off-piste skiers in the Expansion Area transects the Whistlers Creek Area. Should this area be removed from Marmot Basin's leasehold, Jasper National Park and Marmot Basin should enter into discussions as to the best alternative for snowmachine access between the Marmot Basin parking lot and the new chairlift in the Expansion area.

- **Use best practices for all future developments**. We recommend that all potential future ski related infrastructure be selected based on best available equipment to reduce disturbance to caribou and other wildlife. This includes noise reduction (chairlift and other sounds such as music) and selecting a chair size to avoid large crowds at the base of the chairlift in the Expansion Area.

- **Prohibit cutting of trees in the expansion area.** Unless absolutely necessary, we recommend prohibiting the cutting of trees to create more open areas for ski runs.

- **Restrict snowmachine travel**. Snowmachine traffic along the egress trail should be minimized. Regular work trips should be scheduled to restrict travel during certain periods of the day and avoid extending the disturbance throughout the entire day. When multiple trips are required as for transporting equipment, we recommend that snowmachines ride in convoys. On days of very high traffic, we recommend instituting no-travel times several times throughout the day to allow animals that may be present to cross the egress trail if they choose to leave the expansion area. More stringent restrictions should be developed if caribou are reported in the Expansion or Whistlers Creek areas.

- **Examine implications of skiers on hiking trails**. Wolves selected areas near hiking trails in winter. Consideration should be given to potential effects of skiers and associated compaction of trails on increasing wolf travel efficiency in winter, when caribou select subalpine habitats. Given the potential population level implications of increased predation risk to caribou, we suggest limiting and/or restricting skiers or motorized vehicles in caribou range.

5.2 Suggested Future Research

- **Monitor physiological stress of caribou**. We recommend that a scat collection protocol for the Tonquin population be established. Specifically, we recommend systematic collection of samples from animals located near Marmot Basin in winter, visible from hiking trails in summer, and in areas of no known stress in both seasons as a baseline. Accurate deposition locations could help

determine the potential level of stress and the zone of influence of disturbances. This exercise could also elucidate whether there are differences in sensitivity between the sexes, and contribute to greater knowledge of sex-related differences in habitat selection.

- **Conduct periodic aerial caribou surveys**. Information from collared caribou provides high quality information on the probability that caribou select areas near Marmot Basin based on available habitat types. However, these data do not provide an accurate representation of actual caribou use in the area. We recommend flying predetermined transects around Marmot Basin during the winter ski season to establish a baseline of male and female caribou use, particularly within the 5km estimated footprint. Flights could be timed before scheduled avalanche control. Should caribou be located in the vicinity, control should be postponed until animals have moved away. If control needs to occur for safety reasons, then a subsequent flight could be conducted to monitor movement of caribou and evaluate the impact of noise. This information would be valuable to address the potential future disturbance to caribou should additional avalanche control be necessary with an expansion.

- **Collar male caribou**. All models and estimated footprints presented in this report are based on collared female caribou. If JNP is considering future collaring of caribou, we recommend that a portion of collars be deployed on males. Any information on male habitat selection would be useful to validate female models and adjust maps to better represent the needs of the entire population.

- **Analyze wolf and caribou movements in vicinity of hiking trails**. We recommend using information from all park wolf data to specifically address summer wolf movements near hiking trails in caribou habitat, to determine if there is a temporal pattern to the selection. Similarly, an analysis of possible correlations between tourist activity and the distance of caribou to hiking trails in alpine areas (night versus day and during high and low tourist season) could inform best practices for managing tourist traffic on hiking trails in sensitive caribou habitat.

- **Monitor wolf use of hiking trails in the Tonquin range during winter**. Evaluate feasibility of monitoring wolf tracks on park trails during winter aerial work.

- **Continue investigating caribou mortality and monitoring recruitment**. These population parameters are critical to understanding present and future mortality risk and for predicting longer-term population viability.

- **Monitor potential caribou use of the mineral lick in Whistler Creek**. A remote camera could help determine if caribou present in the area are attracted to and use the mineral lick.

- **Continue monitoring total range disturbance and establish activity levels**. We estimated that approximately 16-22% of the habitable area in the Tonquin range is disturbed by human

activities and fire. We recommend that JNP staff continue updating this information based on criteria from the Scientific Review until such time that criteria specific to Mountain caribou are established. Systematic collection of activity information in association with physical infrastructure and trails would also contribute to greater understanding of caribou response and refine mitigation measures.

6.0 APPENDIX

6.1 Base Seasonal Caribou Habitat Models

6.1.1 RATIONALE

The analysis of the potential impact of Marmot Basin and expansion into the Tres Hombres and Outer Limits areas requires seasonal base habitat models that provide a measure of the perceived habitat quality within different areas of the Tonquin Range. These base models can then be used as a reference for more specific analyses. We use weighted distributions to estimate Resource Selection Probability Functions (RSPFs) in the case of the use-available design (Lele and Keim 2006, Lele 2009). An RSPF is a function that describes the probability that a particular resource, as described by a series of environmental covariates, will be selected by an individual animal (Manly et al. 2002). Recent advances in computational algorithms make it possible to estimate probability of selection with various models including logistic, loglog, and probit. Because of the variation in data quality between individual caribou, we use models to rank habitat quality and not to estimate the actual probability of patch selection. However, these models usually are a more accurate representation of natural processes compared to more commonly used exponential models.

6.1.2 METHODS

6.1.2.1 Caribou Data

Our original dataset contained 72,728 GPS collar locations from 15 female Tonquin caribou from 2002 to 2009 (Table 2). Capture and collaring details are available in annual progress reports available from Parks Canada. The number of locations per caribou was variable and depended on the year, type of collar, and fix frequency programmed.

Table 2: Original Seasonal GPS collar data available for analysis (Tonquin caribou 2002-2009).

	Date				
Season	Start	End	Duration (days)	Weeks	Num. Locations
Calving	23-May	20-Jun	29	22-25	5,429
Post-Calving	21-Jun	19-Jul	29	25-30	5,084
Summer	20-Jul	26-Sep	69	30-39	11,748

Rut	27-Sep	31-Oct	35	39-44	5,489
Early Winter	1-Nov	21-Jan	82	44-3	17,593
Late Winter	22-Jan	22-May	120	3-22	27,385
				Total:	72,728

6.1.2.2 GIS Layers

We generated 34 GIS layers to describe the Tonquin caribou range (Table 3), divided into 3 categories: topographical, landscape/vegetation, and anthropogenic. We used a Digital Elevation Model (DEM) to derive slope and aspect (ArcGIS, Spatial Analyst). Aspect was then interpreted in two different ways: first, as a categorical variable with slopes smaller than 5 degrees classified as flat terrain (north is the reference category in regression analyses) and second, as a measure of southern exposure (-1 x cos (Aspect)). Terrain Ruggedness was estimated using a vector ruggedness measure (VRM, Sappington et al. 2007).

The JNP hydrology database layer only covered the Alberta portion of the Tonquin study area. We used the National Topographic Data Base (NTDB, Geogratis – Natural Resources Canada) to generate maps of the western (British Columbia) portion of the study area. Some larger streams were classified as waterbodies in the NTDB but large streams in the Jasper database. We extracted the NTDB polygons of streams and merged them to the linear stream layers for consistency with the JNP hydrology database.

We generated vegetation layers for the entire range by modifying BC Vegetation Resource Inventory (VRI) information (British Columbia Ministry of Forests, Lands and Natural Resource Operations) to match, as accurately as possible, the Jasper Ecological Land Classification (ELC, Holland and Coen 1983) vegetation layers. Most of the vegetated Tonquin landscape consisted of 4 of the 17 ELC classes:

6. Cool moist lower subalpine lodgepole pine
7. Lower subalpine Englemann spruce and subalpine fir
8. Upper subalpine spruce, subalpine fir and larch
9. Non-forested lands with rarely burned vegetation
10. **Rock/Ice**
11. **Water**

We used a combination of DEMs and VRI species composition layers to identify classes 1-3 listed above in the BC layers. Lower subalpine classes 1 and 2 were generated by extracting VRI information between 1,350 and 1,900 m of elevation (Holland and Coen 1983) and generating individual layers for pine and spruce leading areas. These layers were then merged to the corresponding ELC classes from the east

portion of the Tonquin range. Upper subalpine conifer in Jasper (class 3 from above) has a lower elevational limit of 1,900m (Holland and Coen 1983). We extracted VRI habitat information above this limit and merged it with the Jasper ELC. Most VRI polygons in this range were open conifer and had either spruce or pine or fir as the leading species and corresponded well with the Jasper ELC. Forest age information from the VRI was merged with the JNP Stand Origin database and standardized.

The non-forested vegetation class was created by merging the *non-forested with rarely burned vegetation* layer from the Jasper ELC to the non-forested Earth Observation for Sustainable Development (EOSD, National Forest Information System – www.ca.nfis.org) classes (shrub tall, shrub low, herb, and grassland). We used AGCC because it more accurately identified alpine areas than the VRI, which often classified alpine vegetation with Rock/Ice. This layer was then used to generate a raster of non-vegetated patch size. All vegetation layers were then resampled at 3 different scales (100m, 1km, 10km). Future comments regarding scale refer to the buffer distance that best fits caribou selection. The term "fine scale habitat selection" is used if caribou selection is best at the 100m scale because it indicates they are selecting for micro habitat features. The term coarse scale is used if caribou selection is best at 500m or 1km scale.

Access in the Tonquin range consists of the Marmot Road, the Cavell Road, and hiking trails. Because of the low level of access, we chose to merge all roads and trails into a common layer to use access as a potential covariate in models. We generated the linear feature layer by merging the roads, trails, and unofficial trails provided by JNP. All Tonquin layers were converted to 30m x 30m rasters for analysis and all work was completed using ARCGIS (10.0) and Geospatial Modelling Environment (version 0.5.5, www.spatialecology.com).

Table 3. List of GIS layers generated for the habitat selection analysis of the Tonquin caribou population, Jasper National Park (2002-2009)

Map No.	Map Name	Unit	Source	Range	Decription
Topographical					
1	DEM_km	km	DEM	0.7-3.4	Elevation from Digital Elevation Model
2	southern_asp	degrees	DEM	-1 to +1	Southern aspects (-1 x cos (Aspect))
3	Aspect_deg	degrees	DEM	0-360, -1 flat	Aspect in degrees with flat terrain having values of -1
4	Apect_5	NA	DEM	1-5	1=North, 2=East, 3=South, 4=West, 5=flat (<=5degreees)
5	Slope_deg	degrees	DEM	0-80	Slope in degrees
6	VRM_5x5	NA	DEM	0-0.5	Terrain Ruggedness (Sappington et al. 2007)
7	all_strm_merg	NA	JNP hydrology and NTS	1 or NoData	All streams
8	dist_strm_km	km	JNP hydrology and NTS	0-10	Distance in km to the nearest stream
9	strm_250_0_1	NA	JNP hydrology and NTS	0 or 1	1 represents rasters within 250m of stream layer
Landscape/Vegetation					
10	non-forested	NA	ELC+EOSD	0 or 1	1 represents the non-forested and rarely burned areas
11	patch_size	km^2	ELC+EOSD	0-45	Pixels represent size of non-forested patch.
12	Dist_alpine_km	km	ELC+EOSD	0-8	Straight line distance to nearest patch of non-forested rarely burned vegetation
13	n_forest_100m	%	ELC+EOSD	0-1	Percent non-forested rarely burned vegetation within a 100m radius
14	n_forest_500m	%	ELC+EOSD	0-1	Percent non-forested rarely burned vegetation within a 500m radius
15	n_forest_1km	%	ELC+EOSD	0-1	Percent non-forested rarely burned vegetation within a 1km radius
16	n_forest_10km	%	ELC+EOSD	0-1	Percent non-forested rarely burned vegetation within a 10km radius
17	upsubalp_01	NA	VRI and ELC	0 or 1	1 represents upper subalpine areas created from conifer treed areas above 1900m in the VRI merged to class 8 in ELC

Table 3 (cont.).

Map No.	Map Name	Unit	Source	Range	Decription
18	up_sublp_100m	%	VRI and ELC	0-1	percent upper subalpine within a 100m radius
19	up_sublp_500m	%	VRI and ELC	0-1	percent upper subalpine within a 500m radius
20	up_sublp_1km	%	VRI and ELC	0-1	percent upper subalpine within a 1km radius
21	up_sublp_10km	%	VRI and ELC	0-1	percent upper subalpine within a 10km radius
22	low_sub_firsp	NA	VRI and ELC	0-1	1 represents lower subalpine spruce and fir areas created from spruce/fir leading treed areas between 1350m and 1900m in the VRI merged to class 6 in ELC
23	lw_spfir_100m	%	VRI and ELC	0-1	percent lower subalpine spruce/fir forest within a 100m radius
24	lw_spfir_500m	%	VRI and ELC	0-1	percent lower subalpine spruce/fir forest within a 500m radius
25	lw_spfir_1km	%	VRI and ELC	0-1	percent lower subalpine spruce/fir forest within a 1km radius
26	lw_spfir_10km	%	VRI and ELC	0-1	percent lower subalpine spruce/fir forest within a 10km radius
27	lw_sub_pin_01	NA	VRI and ELC	0-1	1 represents lower subalpine pine areas created from pine leading treed areas between 1350m and 1900m in the VRI merged to classes 2 and 5 in ELC
28	lw_pine_100m	%	VRI and ELC	0-1	percent lower subalpine pine forest within a 100m radius
29	lw_pine_500m	%	VRI and ELC	0-1	percent lower subalpine pine forest within a 500m radius
30	lw_pine_1km	%	VRI and ELC	0-1	percent lower subalpine pine forest within a 1km radius
31	lw_pine_10km	%	VRI and ELC	0-1	percent lower subalpine pine forest within a 10km radius
32	Dist_edge_km	km	EOSD and ELC		Distance to edge between forested and non-forested areas
33	SA_age_2011	Years	VRI and Stand Origin	0-411	Stand age as of 2011, non vegetated areas have age 0
Anthropogenic					
34	Dist_linear_km	km	JNP roads and trails	0-40	Distance to nearest access

6.1.2.3 Accounting for individual variation in caribou habitat selection

Our primary objective was to develop the most parsimonious predictive models of seasonal caribou habitat selection in the Tonquin Range. RSPFs are data intensive and reducing data per caribou to the lowest denominator would have resulted in insufficient data to generate models. However, not accounting for individual variation in caribou habitat selection can result in biased models (Gustine and Parker 2008) that predominantly capture the selection patterns of animals with the greatest number of locations. Therefore, we used a 3-step modeling process to accurately assess seasonal similarity in individual caribou habitat selection patterns.

We first used the original dataset to develop initial base habitat models with all available data assuming that all caribou had relatively similar selection patterns. Next, we performed RSPF diagnostics on individual caribou within each season and compared general selection strategies among individuals and to global models. Where individual caribou behavior was variable within a season, we grouped individuals by leading habitat type and adjusted data so that the ratio of grouped caribou was within a 10% window of the ratio of caribou locations. When necessary, our data rarefication strategy involved maintaining consistency in location data among individuals. Specifically, some caribou were monitored over several years whereas others only had a single year of location data. Therefore, when data needed to be reduced within a group, we eliminated an entire year of data from those caribou with multiple years of data. Lastly, in seasons where data adjustments were required, we regenerated final base habitat selection models using the reduced datasets. For clarity, here we discuss individual caribou variation but present only final base habitat models.

6.1.2.4 Model Development

We used a manual stepwise model building procedure whereby covariates were individually visually screened and only those covariates with clear selection relationships were considered as potential covariates in seasonal models. Relationships considered in this screening analysis included the exponential, logit, loglog, and probit functions. Within each season, model selection was performed using the relationship that best described selection patterns for the majority of covariates. We considered alternatives to the logit link when AIC score differences were greater than 10.

Model selection was based on forward stepwise inclusion where pre-screened covariates were added sequentially in order of their strength in explaining the data based on Akaike information criterion (AIC; Burnham and Anderson 2002) and visual inspection. RSPF estimation requires at least one continuous covariate; therefore, seasons where the best 2 covariates were categorical required the addition of a subsequent covariate to be estimated. This would only be an issue if more complex models do not improve fit. When covariates were highly correlated ($r>0.6$), we only considered the variable that provided the better fit to avoid collinearity issues (Hosmer and Lemeshow 2000). When biologically appropriate, we also tested the fit of second order transformations. This pluralistic approach

incorporates advantages of hypothesis testing and information theory (Stephens et al. 2005, 2007). We generated 10,510 random locations with the study area (density of 1/0.1km^2) to represent available habitat.

We identified the most parsimonious models based on Akaike's Information Criterion using the cutoff of 10 for distinguishing differences in models (AIC, Burnham and Anderson 2002, p70 for difference in AIC), Area Under the receiver operating characteristic Curve (AUC), and Variance Inflation Factors (VIF) statistics. Models with the lowest AIC score and highest AUC are considered the best fit to the data. AUC values between 0.7 and 0.8 are considered to have acceptable discrimination and values above 0.8 are excellent (Hosmer and Lemeshow 2000). Variance Inflation Factors provide information on the level of correlation between predictors (VIF values below five are considered acceptable).

We used AUC to measure the discrimination of the model. Specifically, AUC graphs plots true positives (sensitivity) vs. false positives (1-specificity) for a binary classifier system as its discrimination threshold is varied. Therefore, a model with no discriminating power would have an AUC value of 0.5. Generally, AUC values between 0.7 and 0.8 are considered to have acceptable discrimination and values above 0.8 are considered to be excellent (Hosmer and Lemeshow 2000). Final models were also tested with the three link functions not used for model selection.

6.1.2.5 Model Validation

The predictive ability of final RSPF models for each season was tested using a *k*-fold cross validation technique (Boyce et al. 2002). We randomly subdivided the data into 5 groups and used 4 of the groups for model training (re-estimating model coefficients) and the fifth for model testing. The procedure was repeated 5 times for each seasonal model. A Spearman rank correlation between area adjusted frequency of cross-validation points within 10 individual bins and the bin rank was calculated for each cross-validated model.

6.1.2.6 Model Sensitivity

Model sensitivity was assessed in 2 ways. First, we explored the distributions of all model covariates, in all seasons, for all caribou and visually compared them to the distributions in the seasonal full models. Second, we sequentially removed locations from individual caribou from the final datasets and developed individual RSPF models on each reduced dataset. We then visually compared distributions of the covariate values with respect to the final seasonal models. This visual sensitivity analysis provides a detailed view of the variability built into the seasonal models from the variation in individual caribou behavior.

6.1.3 RESULTS

6.1.3.1Final Datasets for Analysis

Individual caribou behavior was relatively consistent between individuals and well captured by the initial global models during the calving, post-calving, summer, and rutting seasons. Therefore, we retained all animal locations from the original datasets to generate final models for these seasons.

During early winter, caribou selected for several habitat groups and selection varied between individuals. Because almost all caribou were monitored throughout the entire season, we assume that the variability observed between individuals represented the variability of the population between 2002 and 2009. We divided caribou into groups depending on the habitat group that they had strongest selection for. Specifically, caribou were divided into non forested leading (43%), upper subalpine leading (43%), and low fir/spruce leading (14%) categories. We achieved a consistent ratio (within 10%) between animals and locations within a group by using only 1 complete year of seasonal data from those caribou where multiple years of data were available and retained the year with the most complete dataset. The early winter dataset was reduced to 14,371 locations.

During late winter, individual caribou habitat selection also was variable between caribou and we identified three general habitat selection patterns. Specifically, we divided caribou into non forest leading (25%), upper subalpine leading (33%), and low fir/spruce leading (30%) categories. Similarly to early winter, we achieved consistency between animal and location ratios by retaining only the best year of data for caribou that were monitored for multiple years. The late winter dataset was reduced to 22,708 locations.

6.1.3.2 Seasonal Base Models

Calving

1. Individual Caribou Habitat Selection Patterns

Caribou selected almost exclusively for non-forested alpine habitat during the calving season. 8 caribou (97% of locations) had sufficient data for individual exploratory analysis (Figure 31). Seven of the 8 caribou had locations throughout the entire calving season. The 7 caribou with data throughout the season selected almost exclusively for higher elevation non-forested habitat. The only exception was caribou 64 that also selected for upper subalpine and low pine. Caribou 59 only had locations for the first part of the calving season and selected primarily for upper subalpine. Caribou 21 showed selection for the “other” class which in fact indicates selection for non-forested habitat and a result of map layers inadequately differentiating between rock/ice and non-forested habitat. This issue will not affect the final base habitat model because it will only have a small effect at the 1km scale used (see next section). Overall, we considered individual caribou selection for general habitat types to be sufficiently similar and well represented by the global model (Figure 32) to justify using all available caribou locations during the calving season.

Figure 31. Tonquin caribou locations during the calving season (May 23rd to June 20th) from 2002 to 2009.

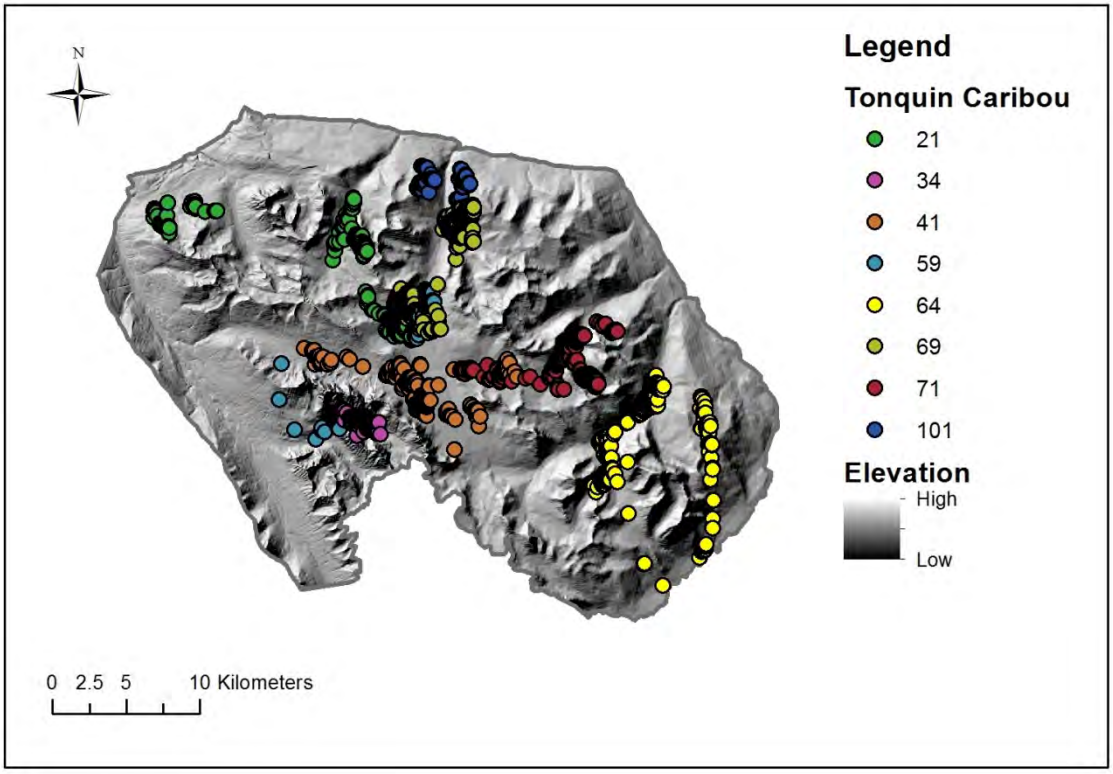
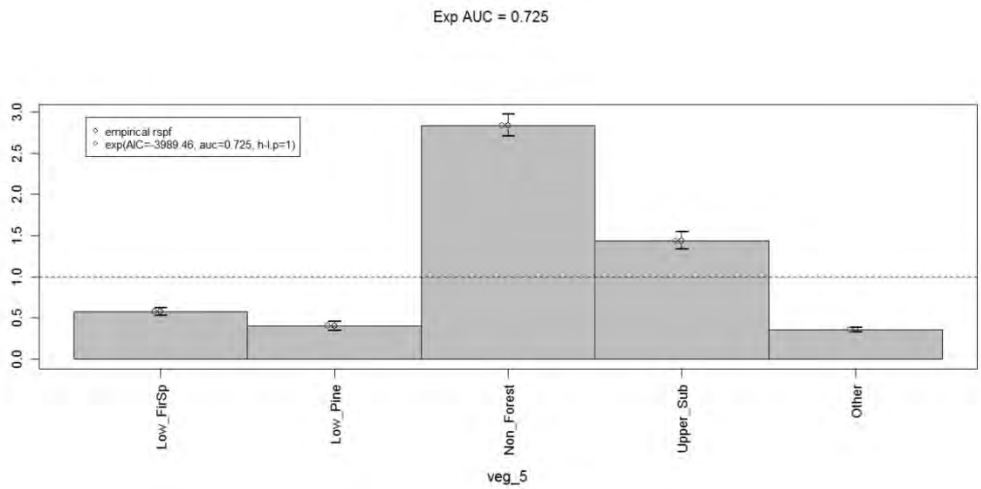


Figure 32. Tonquin caribou selection for covariate Veg_5 during the calving season (May 23rd to June 20th) using the full final dataset (2002-2009).



2. Distributions of Potential Model Covariates

Generally, the logistic curve offered the best fit to the data and covariate plots are presented below in order of best predictive values based on AIC scores (Figures 33-39). Only those variables with clear selection patterns are presented here and considered as covariates for the final model.

Selection for non-forested habitat at the 500m scale was best predicted with a second order logistic curve (Figure 33), however, we chose to use the first order for model building because selection for areas of 100% non-forested habitat was not well captured by the second order model. In addition, this allowed us to save a degree of freedom and significantly reduce model complexity and facilitate interpretation.

Caribou selected primarily for flat terrain and then for south and west facing slopes of up to 20 degrees (Figures 34 and 36). Slope was best modeled with a first order loglog link. The second order logistic curve best described caribou selection for elevations between 1700m and 2400m.

Selection for upper subalpine habitat at the 1km scale and terrain ruggedness were best predicted by the first order logistic curve (Figure 37) whereas distance to forest edge was best represented by the first order loglog link (Figure 38).

Figure 33. Tonquin caribou selection for percent non-forested habitat at the 500m scale during the calving season (May 23rd to June 20th) using the full final dataset (2002-2009).

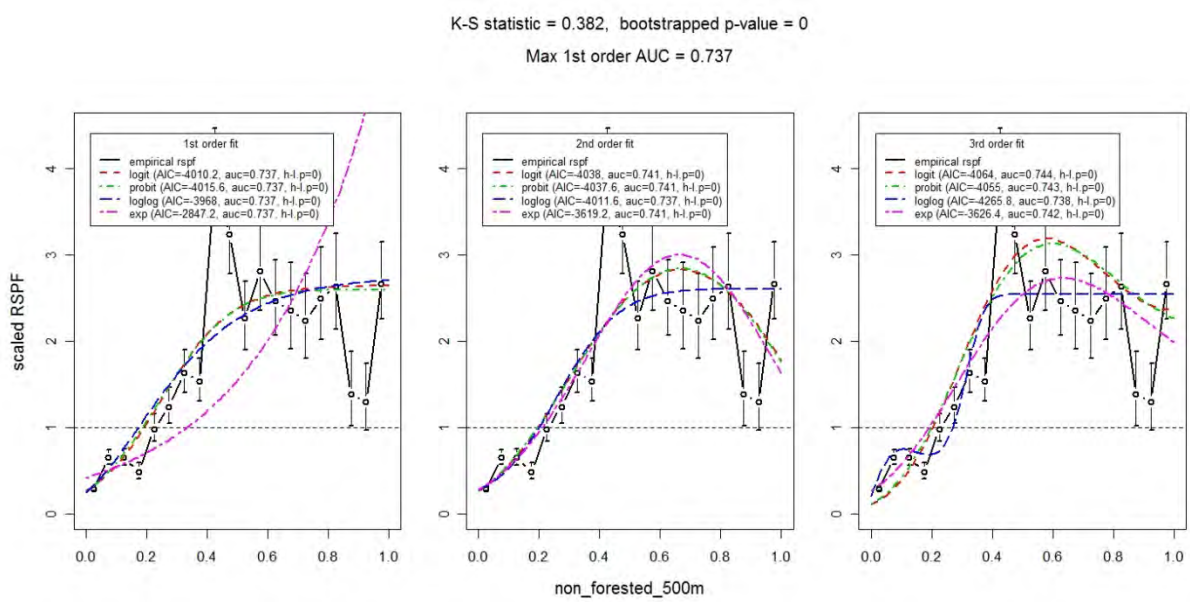


Figure 34. Tonquin caribou selection for slope during the calving season (May 23rd to June 20th) using the full final dataset (2002-2009).

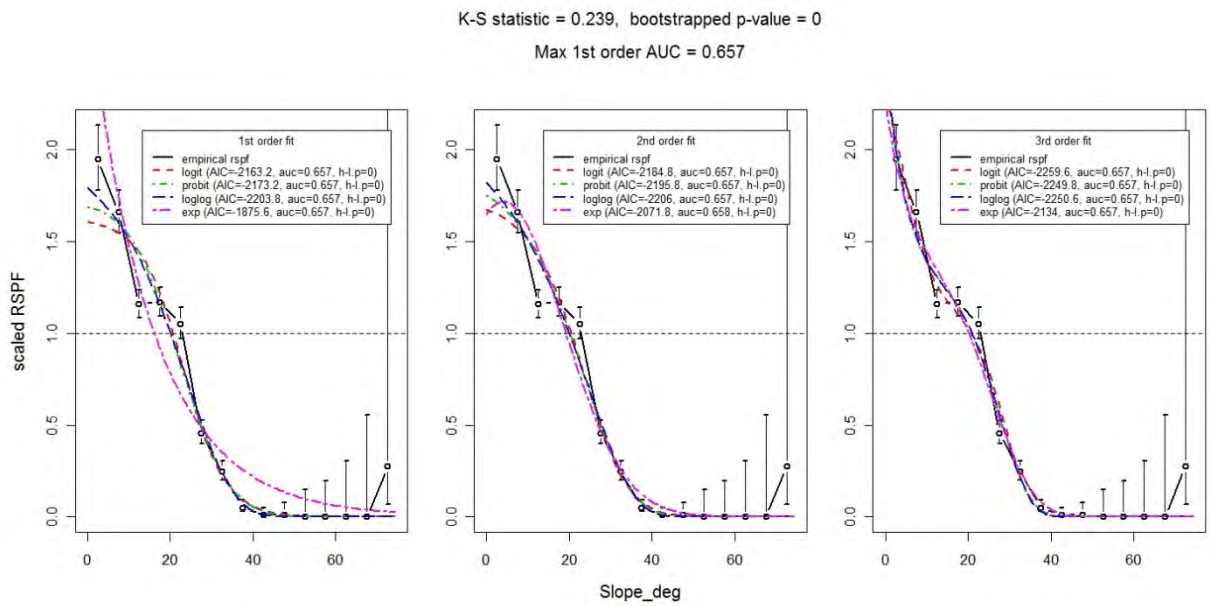


Figure 35. Tonquin caribou selection for elevation (km) during the calving season (May 23rd to June 20th) using the full final dataset (2002-2009).

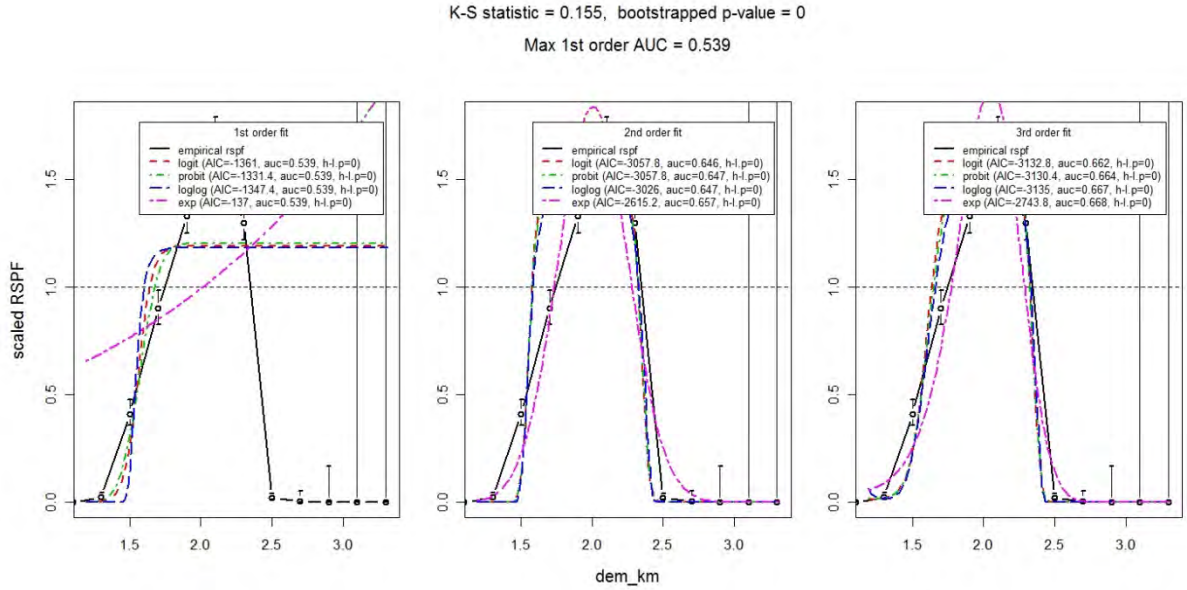


Figure 36. Tonquin caribou selection for aspect during the calving season (May 23rd to June 20th) using the full final dataset (2002-2009). Areas with slope below 5 degrees were considered flat.

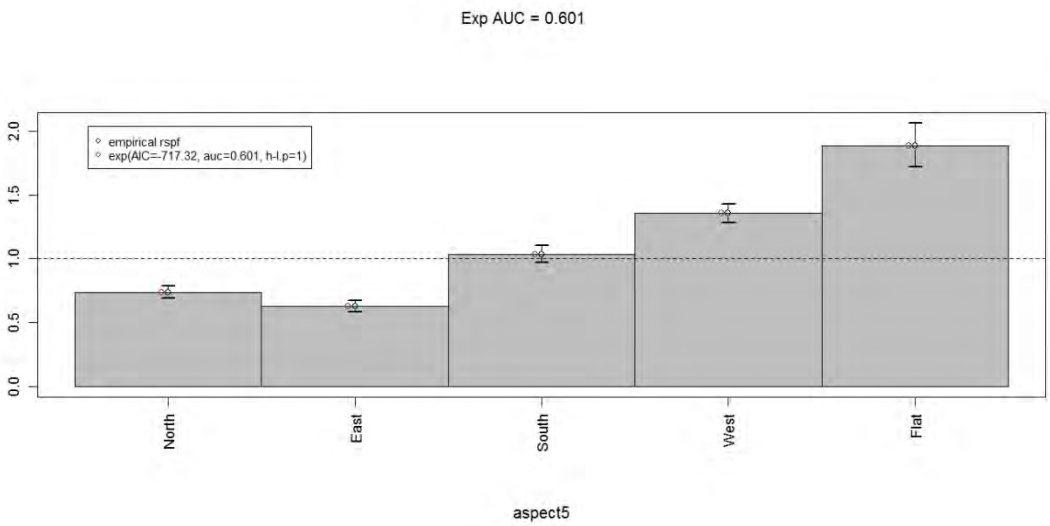


Figure 37. Tonquin caribou selection for percent upper subalpine habitat during the calving season (May 23rd to June 20th) using the full final dataset (2002-2009).

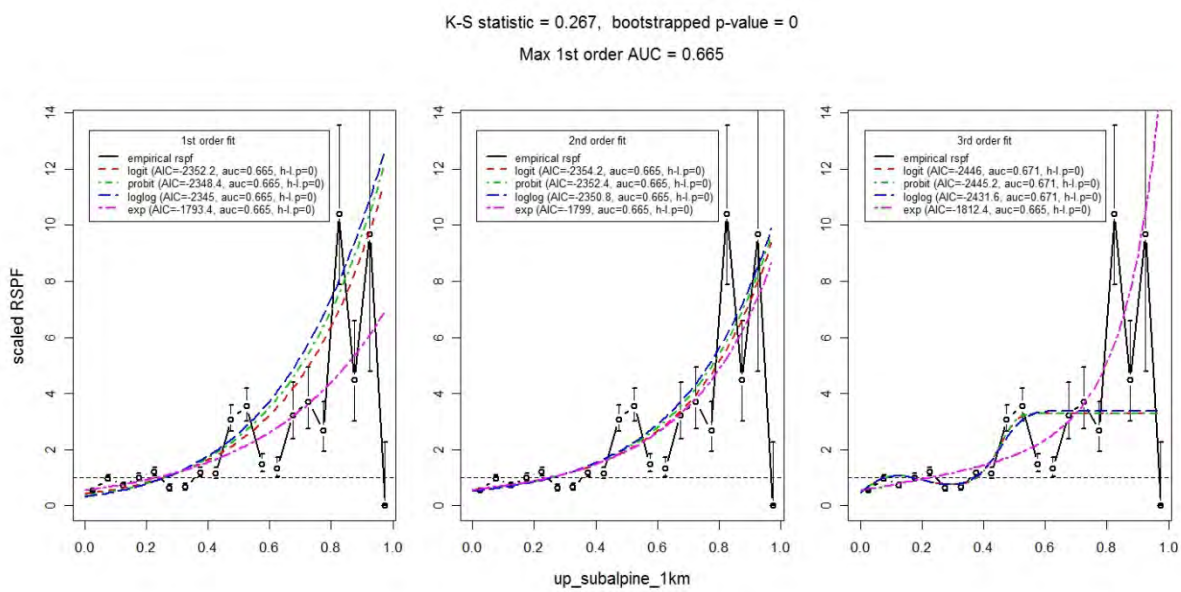


Figure 38. Tonquin caribou selection for distance to forest edge during the calving season (May 23rd to June 20th) using the full final dataset (2002-2009).

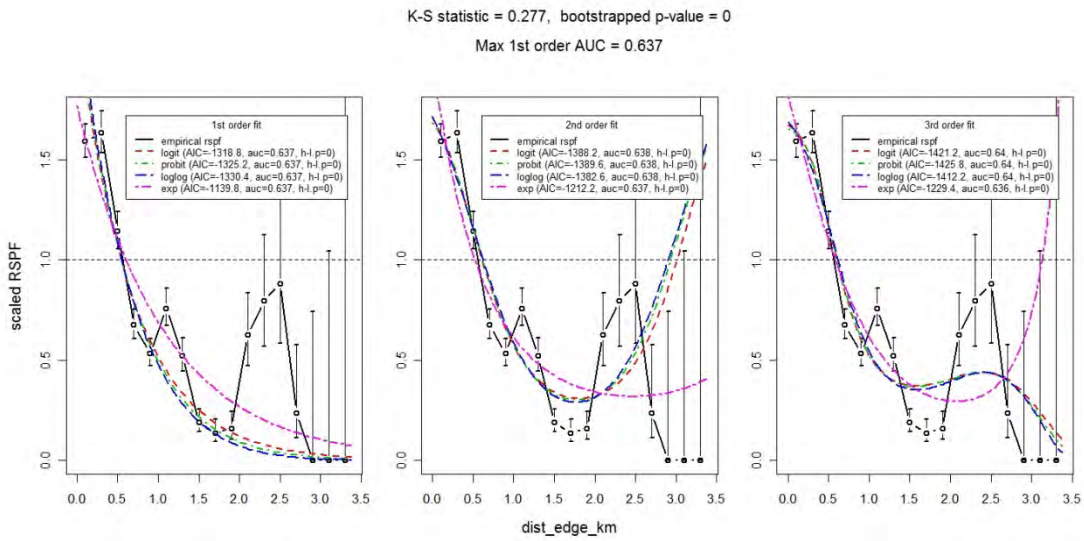
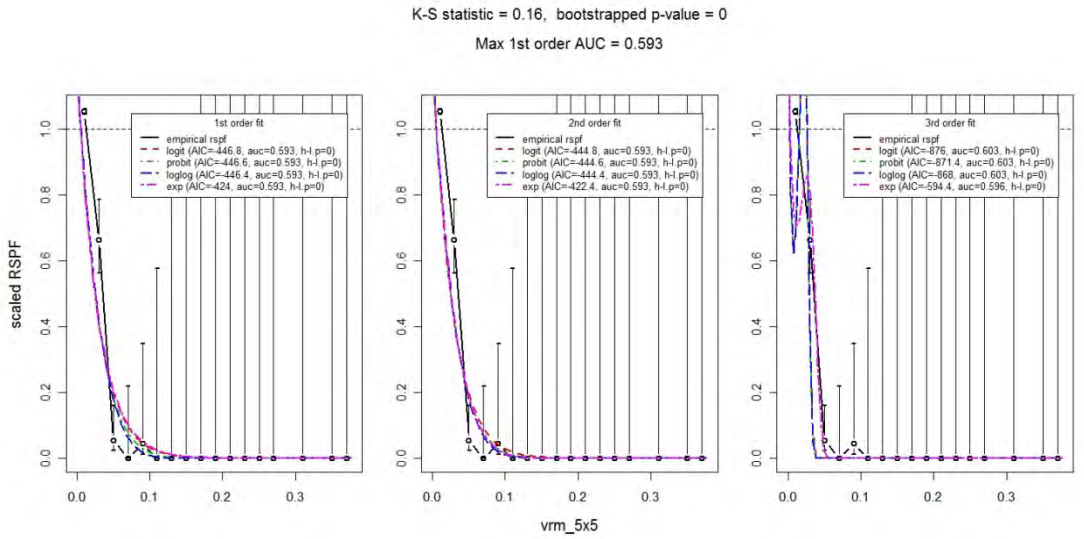


Figure 39. Tonquin caribou selection for terrain ruggedness (VRM_5x5) during the calving season (May 23rd to June 20th) using the full final dataset (2002-2009).



3. Base Habitat Model

Caribou habitat selection during the calving season was characterized by selection for higher elevation alpine habitats and was well described by the final model (Table 4). The percent non-forested habitat at the 500m scale was a stronger predictor of caribou habitat selection than the categorical "Veg_5"

covariate and was therefore included as the first entry in the final model. Selection for upper subalpine was linear only at the coarser 1km scale, whereas finer scales would have required a second order transformation; probably because caribou spent most of their time in the alpine and some in the subalpine. In addition, caribou selected for areas closer to forest edge, which were associated with the non-forested/upper subalpine boundary. Selection was greatest for flat terrain and west facing slopes of up to 20 degrees. The logit link provided the best fit to the data in the final model (Table 6) and average cross validated Spearman Rank Correlation was 0.84 (Table 7).

Table 4. Forward stepwise selection of covariates during the calving season (May 23rd to June 20th) for Tonquin caribou (2002-2009). Covariates are listed left to right in order of their explanatory strength. The best model has the lowest AIC score and is bolded.

Model	Non forested 500m	Slope deg	DEM^2	Aspect 5	Up sub 1km	Dist edge	VRM 5x5	AIC	AUC	MAX_VIF
1	X	X						-5635	0.769	1.0
2	X		X					-5315	0.761	1.2
3	X			X				-4419	0.746	1.6
4	X				X			-5152	0.763	1.0
6	X					X		-4220	0.740	1.1
8	X						X	-4555	0.748	1.0
9	X	X	X					-6728	0.791	1.4
12	X	X		X				-6045	0.779	1.6
10	X	X			X			-6539	0.786	1.1
11	X	X				X		-5950	0.775	1.2
13	X	X					X	-5752	0.770	1.1
16	X	X	X	X				-7006	0.796	1.7
14	X	X	X		X			-6919	0.794	1.5
15	X	X	X			X		-6756	0.791	1.5
17	X	X	X				X	-6760	0.790	1.6
18	**X**	**X**	**X**	**X**	**X**			**-7445**	**0.803**	**1.7**
19	X	X	X	X		X		-7040	0.796	1.7
20	X	X	X	X			X	-7047	0.795	1.7
21	X	X	X	X	X	X		-7445	0.803	1.7
22	X	X	X	X	X		X	-7437	0.802	1.7

Table 5. Coefficients and standard errors (SE) for Covariates in model 5 for the calving (May 23rd to June 20th) season for Tonquin caribou (2002-2009).

Covariate	Estimate	SE	*Z*	*p*	VIF
(Intercept)	-14.558	0.942	-15.45	<0.0001	NA

non forested 500m	6.350	0.286	22.17	<0.0001	1.4
Slope deg	-0.134	0.005	-28.67	<0.0001	1.7
dem km	14.631	1.012	14.46	<0.0001	1.5
dem km^2	-3.778	0.265	-14.25	<0.0001	1.5
aspect5East	-1.645	0.116	-14.13	<0.0001	1.6
aspect5South	-0.461	0.110	-4.18	<0.0001	1.6
aspect5West	0.925	0.104	8.87	<0.0001	1.6
aspect5Flat	-0.223	0.132	-1.69	0.1416	1.6
up subalpine 1km	4.120	0.174	23.70	<0.0001	1.4

Table 6. Fit statistics from model 5 with alternative link functions. The most parsimonious model is highlighted in bold.

Link	AIC	AUC	Max VIF
Logit	-7445	0.803	1.7
Loglog	-6339	0.799	1.7
Probit	-7277	0.802	1.7
Exponential	-5890	0.797	1.7

Table 7. Cross-validated Spearman-rank correlations (r_s) between RSF bin ranks and area-adjusted frequencies for individual and average model sets for Tonquin caribou during the calving (May 23rd to June 20th) season (2002-2009).

Set	r_s	*P*
1	0.888	0.0006
2	0.879	0.0008
3	0.842	0.0022
4	0.879	0.0008
5	0.565	0.0885
Average	0.811	<0.001

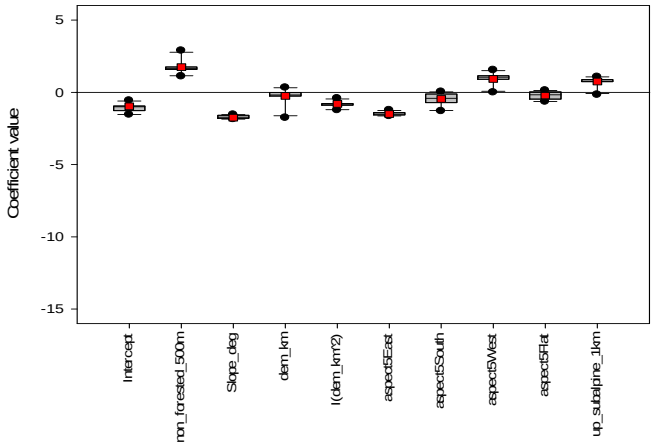
4. Model Sensitivity

Generally, individual caribou selection patterns were consistent with representations of covariates using all available caribou data (Figures 33-39). Furthermore, final model coefficient values were not significantly influenced by the behavior of individual caribou and remained conservative within their range of variation (Figure 40).

Individual caribou patterns for buffered non-forested and upper subalpine habitats clearly showed selection for areas with increasing proportion of these habitat types, however, the model fit was not clear at the individual level owing in part to the size of the dataset. All caribou selected elevations within the 1700m to 2500m described by the final model though individual caribou selected within the upper or lower values of this range apparently depending on their latitudinal location within the Tonquin range. Specifically, caribou in the southern part of the Tonquin range selected for elevation between 1600m and 2000m (caribou 34, 41, 59, and 64) whereas caribou to the north preferred elevations between 2100m and 2400m (caribou 21, 69, 71, and 101). The variation is likely accounted for by the elevational gradient of alpine habitat in different areas of the range.

In the final model, caribou selected primarily for flat terrain and avoided east-facing aspects. This selection pattern is exhibited by 6 of the 8 caribou monitored. The 2 exceptions were caribou 69 and 101 that avoided flat terrain and selected for north and east facing slopes. These 2 caribou had overlapping seasonal ranges in the northern part of the range (Figure 31). In the final model, caribou select for slopes of up to approximately 20 degrees. This is consistent with individual selection patterns of all caribou monitored.

Figure 40. Tonquin caribou sensitivity of standardized covariates during the calving season (May 23rd to June 20th) using the full final dataset (2002-2009). Individual caribou were excluded sequentially and fit with the calving base model RSPF. Red squares represent full base model covariates.



Post-Calving

1. Individual Caribou Habitat Selection Patterns

Caribou selected almost exclusively for non-forested alpine habitat during the post-calving season. Seven of 10 caribou (96% of locations) had sufficient data for individual exploratory analyses and were monitored throughout the entire season (Figure 41). Six of the 7 caribou selected for non-forested habitat and avoided all other habitat classes. The remaining caribou (caribou 34) selected primarily for non-forested habitat but also selected for lower subalpine pine. Overall, we considered individual caribou selection for general habitat types to be very similar and well represented by the global model (Figure 42) and chose to use all available caribou locations during the post-calving season for model development.

Figure 41. Tonquin caribou locations during the post-calving season (June 21st to July 19th) from 2002 to 2009.

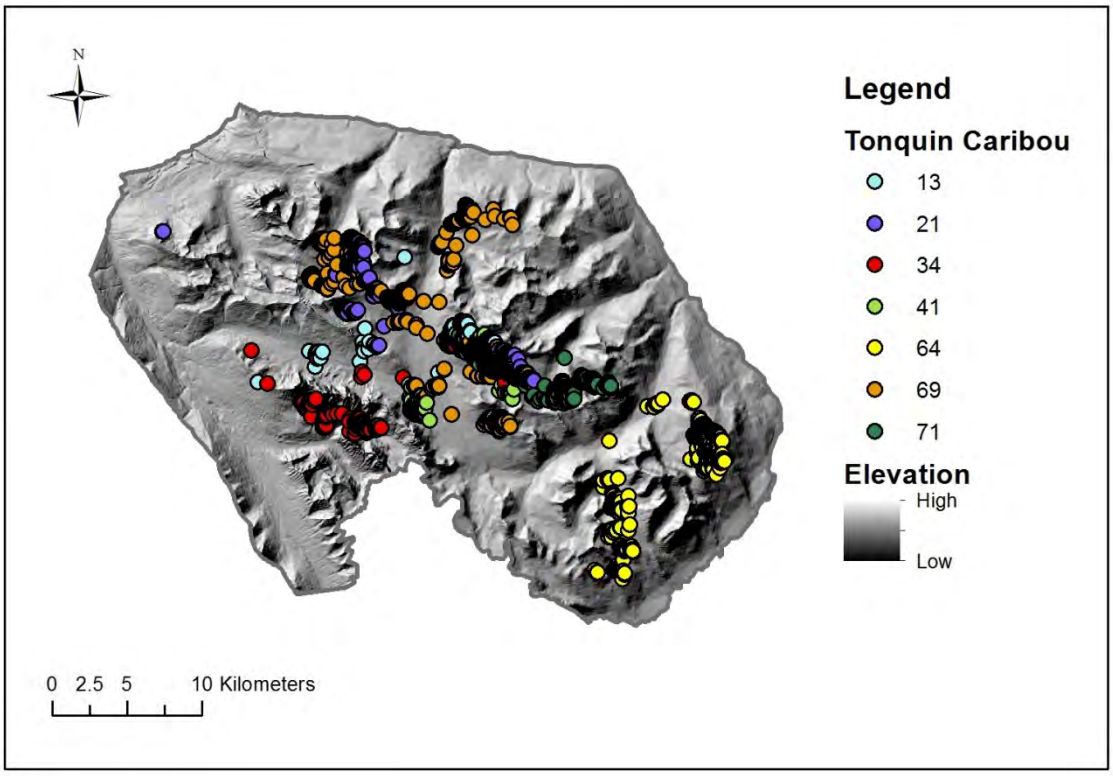
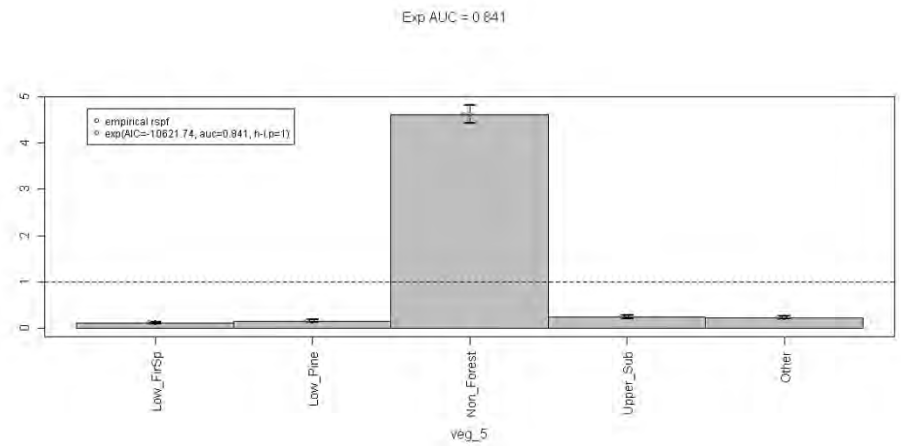


Figure 42. Tonquin caribou selection for covariate Veg_5 during the post-calving season (June 21st to July 19th) using the full final dataset (2002-2009).



2. Distributions of Potential Model Covariates

Generally, the logistic curve offered the best fit to the data and covariate plots are presented below in order of best predictive values based on AIC scores (Figures 43-47). Caribou selected for large alpine patches and areas close to alpine habitat. Based on AIC scores, the loglog curve best fit the selection pattern of patch size (figure 43), however, all models except the exponential fit the data well. The logistic curve best fit the distance to alpine variable (Figure 44).The second order logistic curve best described caribou selection for mid-elevations (Figure 45).

Neither the first or second order slope models captured the pattern of selection between 0 and 5 degrees (Figure 46), however, this behavior is captured by the “flat” category in the aspect covariate (Figure 47). Therefore, we used the first order logistic to describe slope.

Figure 43. Tonquin caribou selection for alpine patch size during the post-calving season (June 21st to July 19th) using the full final dataset (2002-2009).

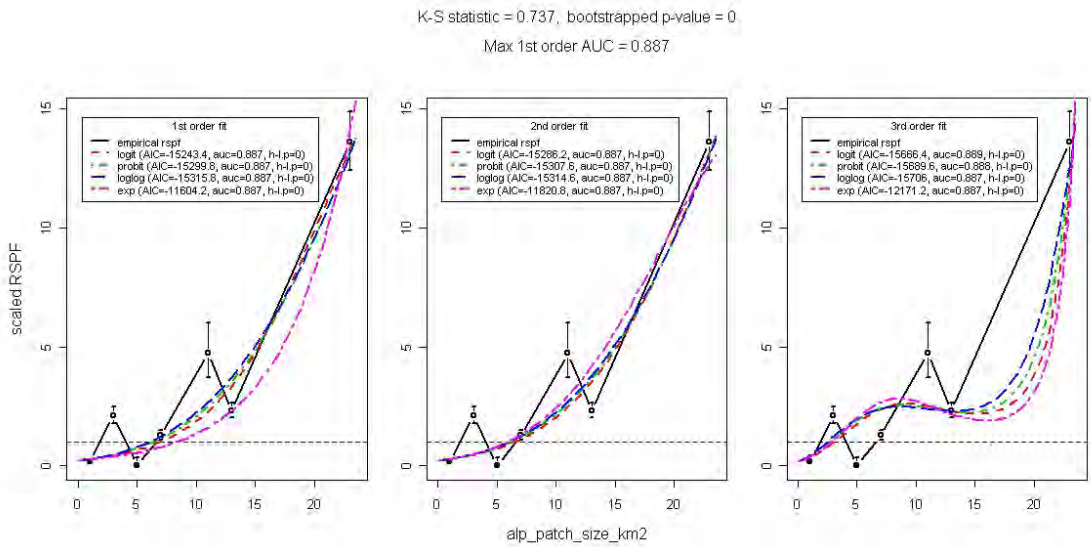


Figure 44. Tonquin caribou selection for distance to alpine during the post-calving season (June 21st to July 19th) using the full final dataset (2002-2009).

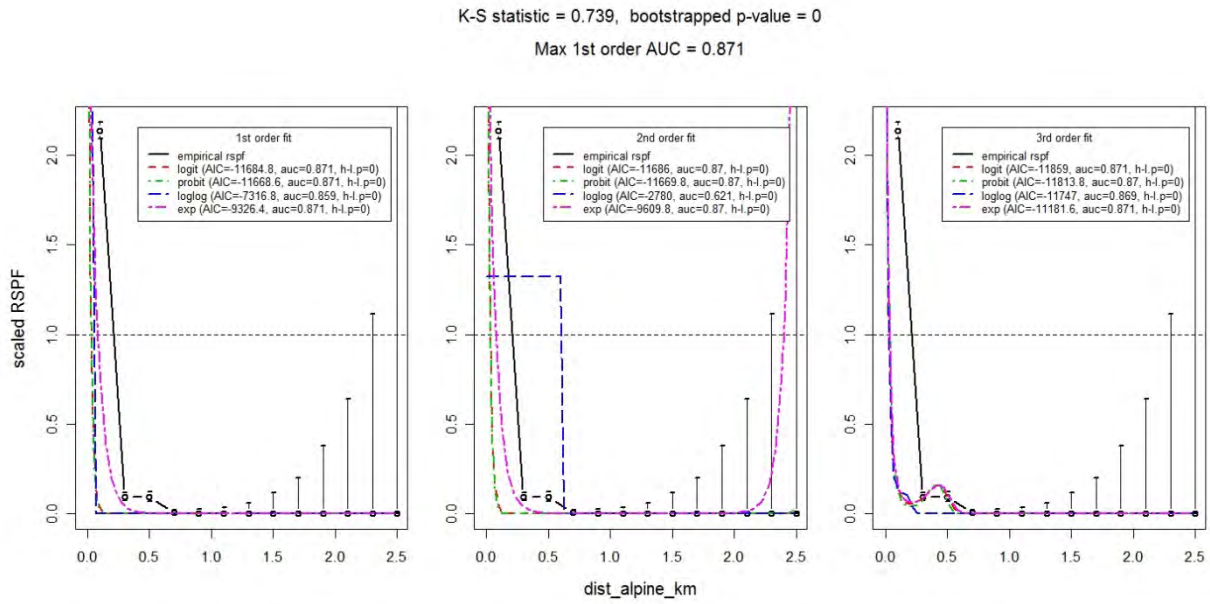


Figure 45. Tonquin caribou selection for elevation during the post-calving season (June 21st to July 19th) using the full final dataset (2002-2009).

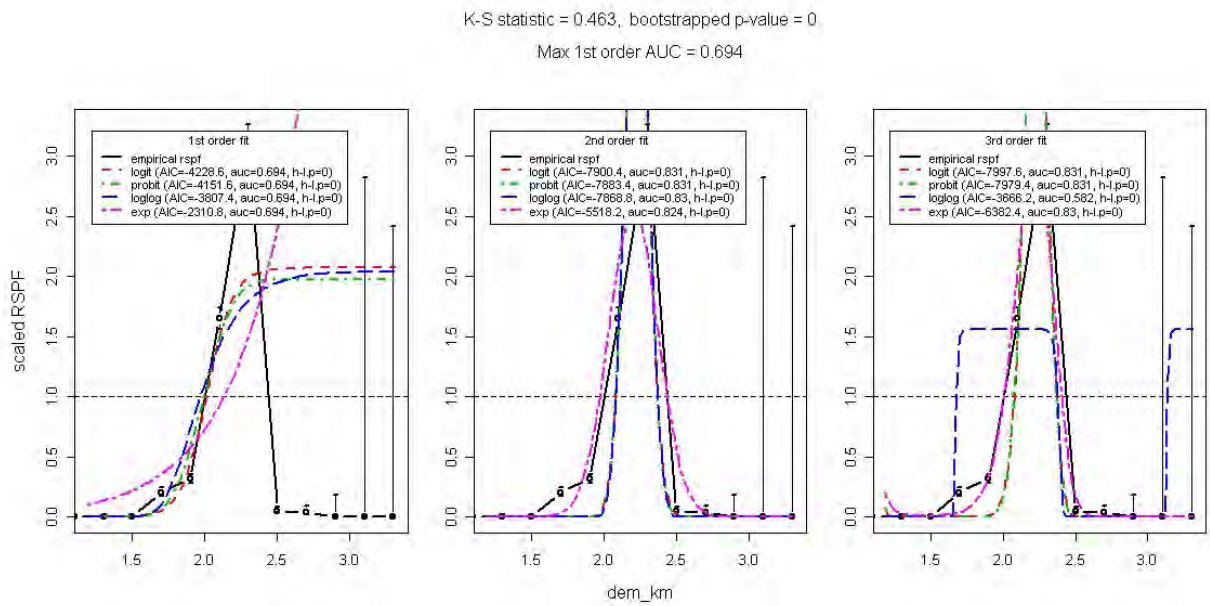


Figure 46. Tonquin caribou selection for slope during the post-calving season (June 21st to July 19th) using the full final dataset (2002-2009).

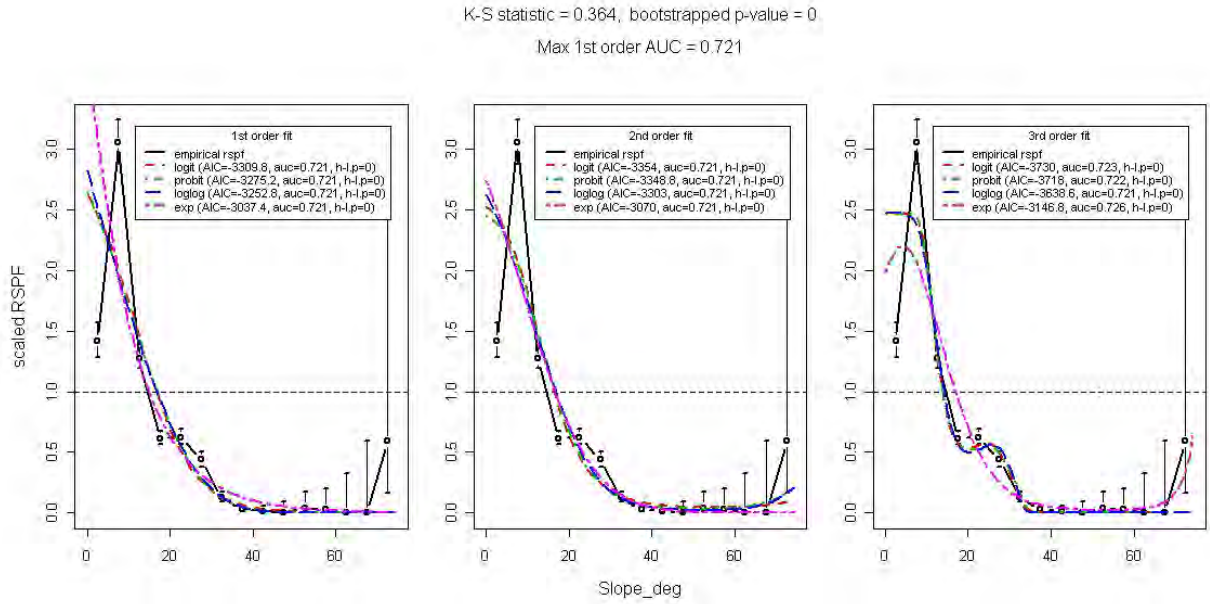
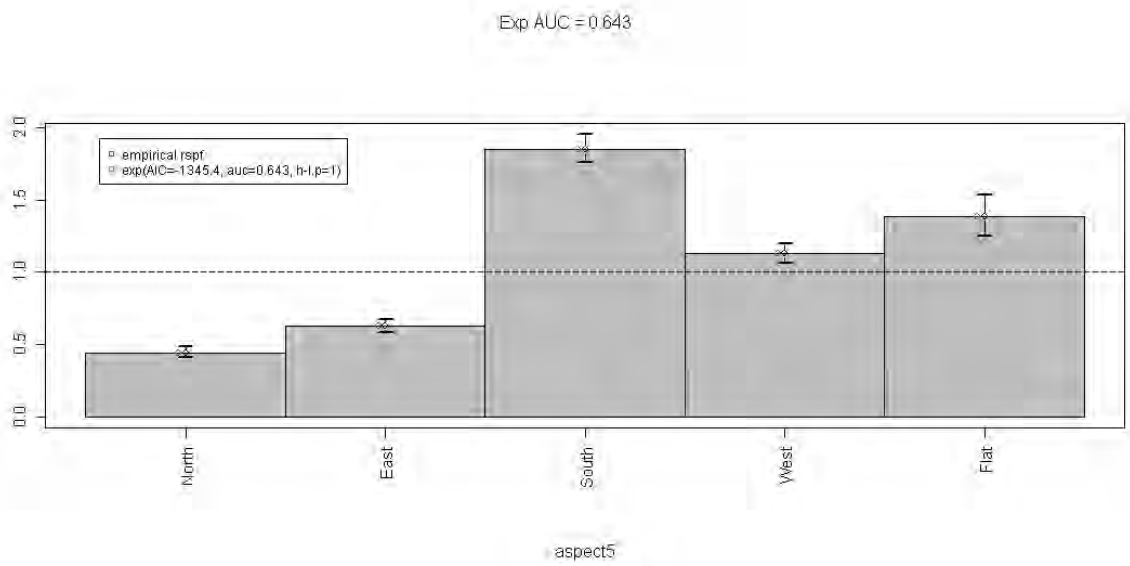


Figure 47. Tonquin caribou selection for aspect during the post-calving season (June 21st to July 19th) using the full final dataset (2002-2009).



3. Base Habitat Model

During the post-calving season, caribou selected almost exclusively for large patches of non-forested habitat and avoided all other vegetation classes. Patch size was a stronger predictor of habitat selection than the categorical "Veg5" covariate and was therefore included as the first entry in the final model (Table 8). Caribou selected for elevations between 2000m and 2500m.

Caribou selected predominantly for 10 degree south facing slopes and then for flat terrain. The logit link provided the best fit to the data (Table 10) and average cross validated Spearman Rank Correlation was 0.78 (Table 11).

Table 8. Forward stepwise selection of covariates during the post-calving season (June 21st to July 19th) for Tonquin caribou (2002-2009). Covariates are listed left to right in order of their explanatory strength. The best model has the lowest AIC score and is bolded.

Model	Patch Size	Dist Patch km	DEM^2	Aspect5	Slope deg	AIC	AUC	Max VIF
1	X	X				-16587	0.920	1.3
2	X		X			-16297	0.894	1.2
3	X			X		-15541	0.877	1.8
4	X				X	-15686	0.894	1.2
5	X	X	X			-17071	0.922	1.6
6	X	X		X		-16859	0.920	1.9
7	X	X			X	-16951	0.923	1.4
8	X	X	X	X		-17218	0.922	1.9
9	X	X	X		X	-17752	0.927	1.7
10	**X**	**X**	**X**	**X**	**X**	**-17979**	**0.926**	**1.9**

Table 9. Coefficients and standard errors (SE) for Covariates in model 10 for the post-calving (June21st to July 19th) season for Tonquin caribou (2002-2009).

Covariate	Estimate	SE	*Z value*	*p*	VIF
(Intercept)	-11.899	4.724	-49.47	0.0118	NA
Patch Size	0.126	0.005	52.31	<0.0001	1.7
Dist Patch	-4.403	0.666	-6.61	<0.0001	1.7
DEM	8.625	3.484	2.48	0.0133	1.5
DEM^2	-2.050	0.814	-2.52	0.0117	1.3
Slope deg	-0.087	0.006	-15.30	<0.0001	1.7
aspect5East	0.777	0.162	4.79	<0.0001	1.7
aspect5South	1.120	0.154	7.28	<0.0001	1.9
aspect5West	0.994	0.159	6.25	<0.0001	1.7
aspect5Flat	-0.065	0.200	-0.33	0.7443	1.6

Table 10. Fit statistics from model 10 with alternative link functions. The most parsimonious model is highlighted in bold.

Link	AIC	AUC	Max VIF

Logit	**-17979**	**0.926**	**1.9**
Loglog	NA	NA	NA
Probit	-17663	0.926	1.9
Exponential	NA	NA	NA

Table 11. Cross-validated Spearman-rank correlations (r_s) between RSF bin ranks and area-adjusted frequencies for individual and average model sets for Tonquin caribou during the post-calving (June 21st to July 19th) season (2002-2009).

Set	r_s	*P*
1	0.758	0.011
2	0.794	0.006
3	0.815	0.004
4	0.799	0.006
5	0.721	0.019
Average	0.777	0.009

4. Model Sensitivity

Generally, individual caribou selection patterns of final model covariates were consistent with representations of covariates using all available caribou data (Figures 43-47), however, there are clear outliers for distance to alpine and elevation (Figure 42). Despite these outliers, final model coefficient values were not significantly influenced and remained conservative within their range of variation (Figure 42).

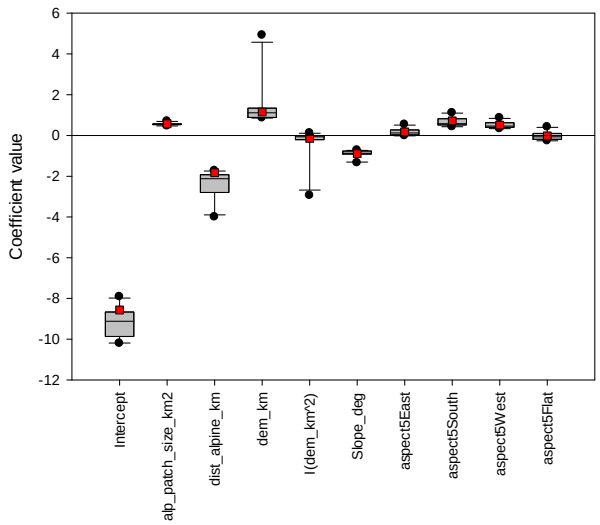
Individual caribou selection patterns for alpine patch size were almost identical for all individuals and showed clear selection for larger patch sizes. The only exception was caribou 64 that exhibited greatest selection for mid-sized patches. However, this caribou ranged over the southernmost section of the Tonquin range where it selected for the largest patch sizes in the area. Therefore, its behavior is consistent with predictions of the final model. Caribou 71 is the patch size outlier visible in Figure 42. This caribou exhibited selection for larger patch sizes similar to other caribou but all models underestimated selection at the higher end of the scale because of the distribution of the data. The final model is not affected by this lack of fit.

All caribou except for caribou 34 selected for elevations between 2000m and 2500m as described by the final model. This caribou selected predominantly for higher elevation alpine habitat but also showed selection for lower-subalpine pine. For that reason, it shows stronger selection for lower elevations than other caribou during this season and is the outlier visible for the elevation covariates (Figure 42).

Because this caribou selected primarily for habitats consistent with other caribou, this slight deviation does not affect parameters significantly in the final model.

Finally, all caribou except 64 showed selection for south and/or flat aspects. This difference did not have an effect on covariate values (as an outlier in figure 42) because this caribou showed little selection for any aspect. In the final model, caribou select for slopes of up to approximately 20 degrees. This is consistent with individual selection patterns of all caribou monitored.

Figure 42. Tonquin caribou sensitivity of standardized covariates during the post-calving season (June21st to July 19th) using the full final dataset (2002-2009). Individual caribou were excluded sequentially and fit with the calving base model RSPF. Red squares represent full base model covariates.



Summer

1. Individual Caribou Habitat Selection Patterns

Caribou selected almost exclusively for non-forested alpine habitat during the summer season. All 9 caribou monitored had sufficient data for individual exploratory analyses and were monitored throughout the entire season (Figure 43). All caribou selected exclusively for non-forested habitat and avoided all other habitat classes. Therefore, we considered individual caribou selection for general habitat types to be very similar and well represented by the global model (Figure 44) and chose to use all available caribou locations during the summer season for model development.

Figure 43. Tonquin caribou locations during the summer season (June 21st to July 19th) from 2002 to 2009.

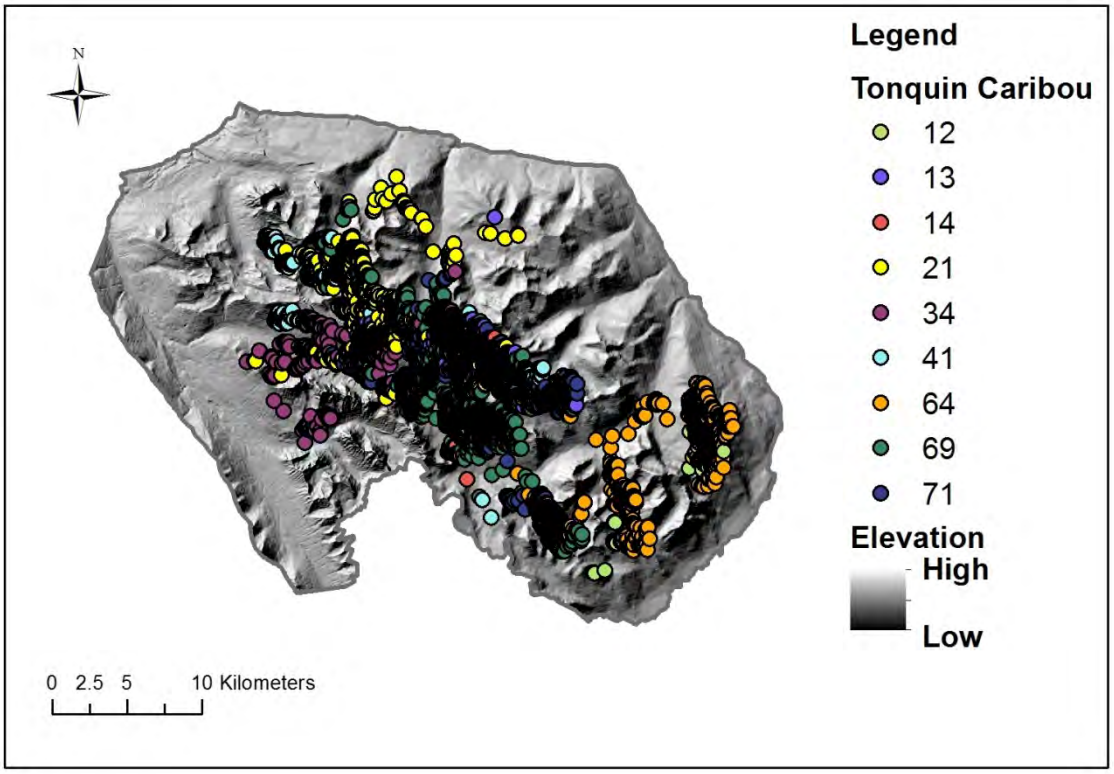
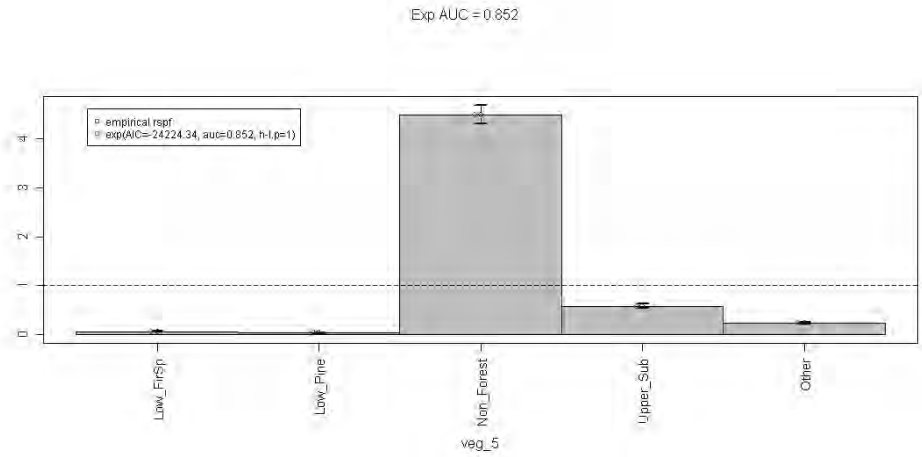


Figure 44. Tonquin caribou selection for habitat types during the summer season (July 20th to September 26th) using the full final dataset (2002-2009).



2. Distributions of Potential Model Covariates

The logistic curve offered the best fit for most covariates and plots are presented below in order of best predictive values based on AIC scores (Figures 45-50). Caribou selected predominantly for large alpine patches. Based on AIC scores, the loglog curve best fit the selection pattern for alpine habitat (figure 45), however, all models except the exponential fit the data well. All models provided good fit for caribou selection for mid-elevations (Figure 46).

Slope was best modeled with a first order logistic (Figure 47) and all models except the exponential provided good fit for caribou selection of linear features (Figure 48).

Figure 45. Tonquin caribou selection for alpine habitat at the 1km scale during the summer season (July 20th to September 26th) using the full final dataset (2002-2009).

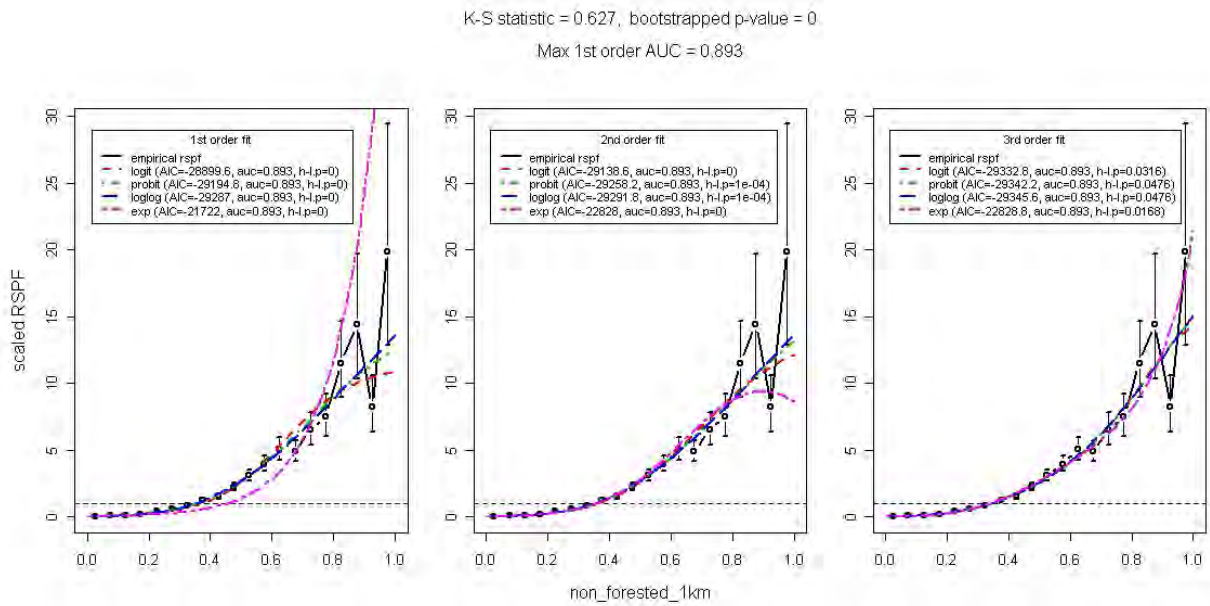


Figure 46. Tonquin caribou selection for elevation during the summer season (July 20th to September 26th) using the full final dataset (2002-2009).

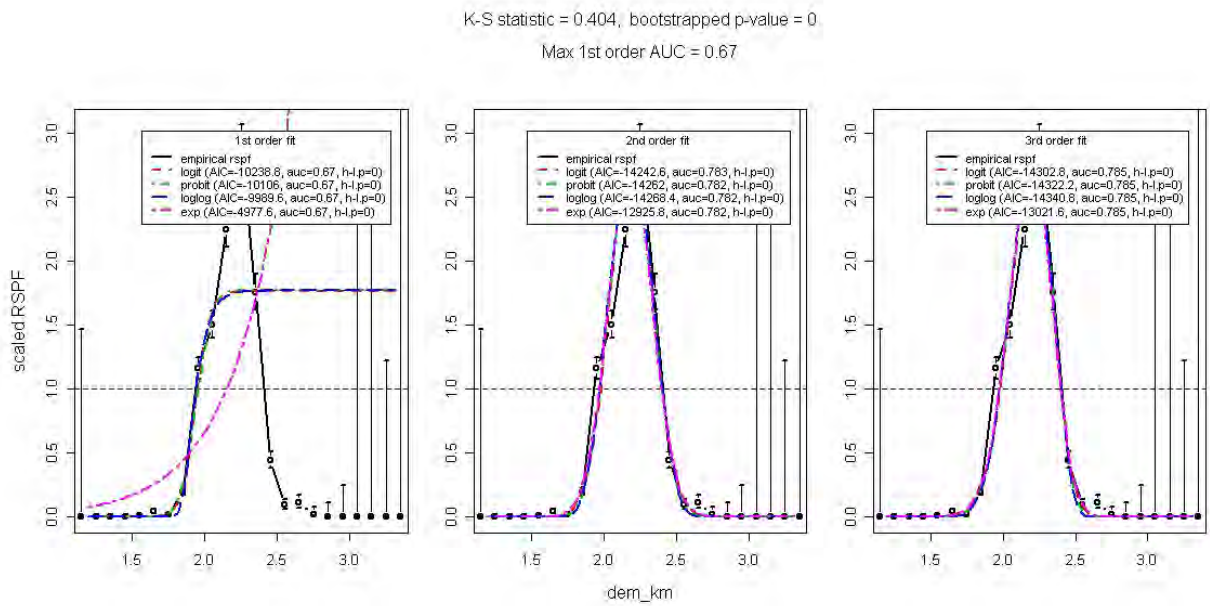


Figure 47. Tonquin caribou selection for slope during the summer season (July 20th to September 26th) using the full final dataset (2002-2009).

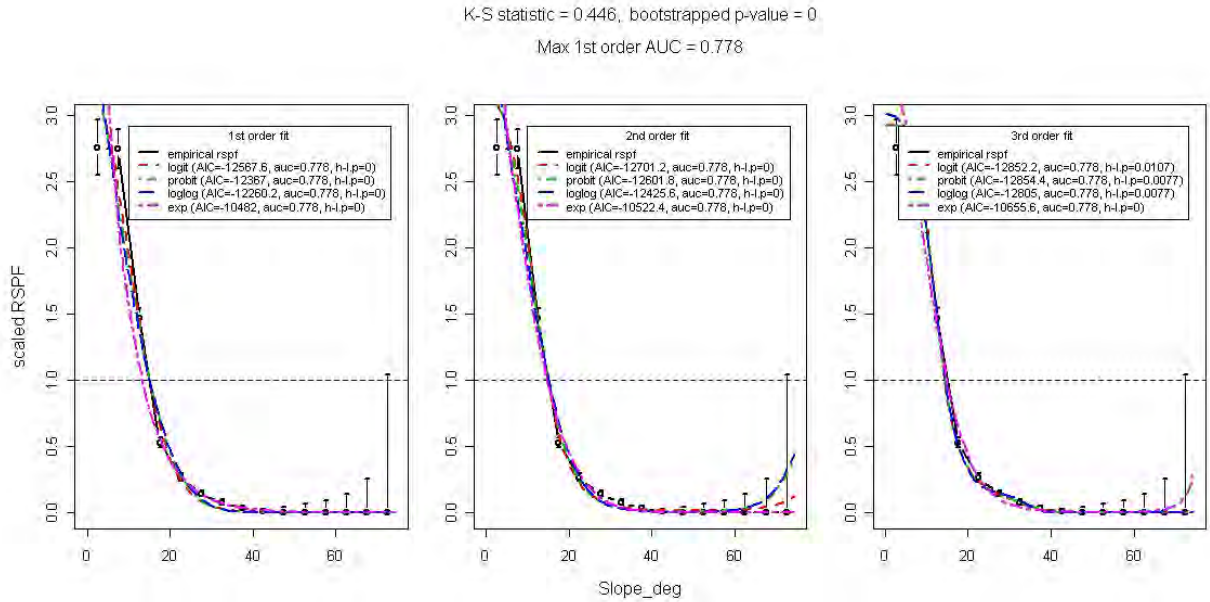


Figure 48. Tonquin caribou selection for the distance to linear features during the summer season (July 20th to September 26th) using the full final dataset (2002-2009).

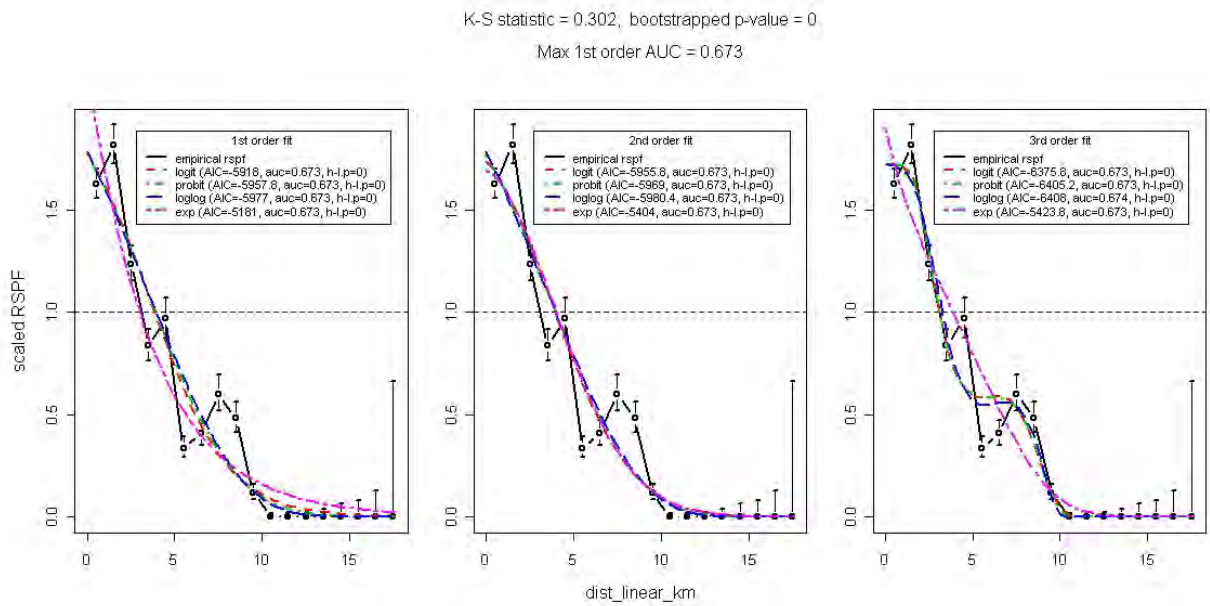


Figure 49. Tonquin caribou selection for aspect during the summer season (July 20th to September 26th) using the full final dataset (2002-2009).

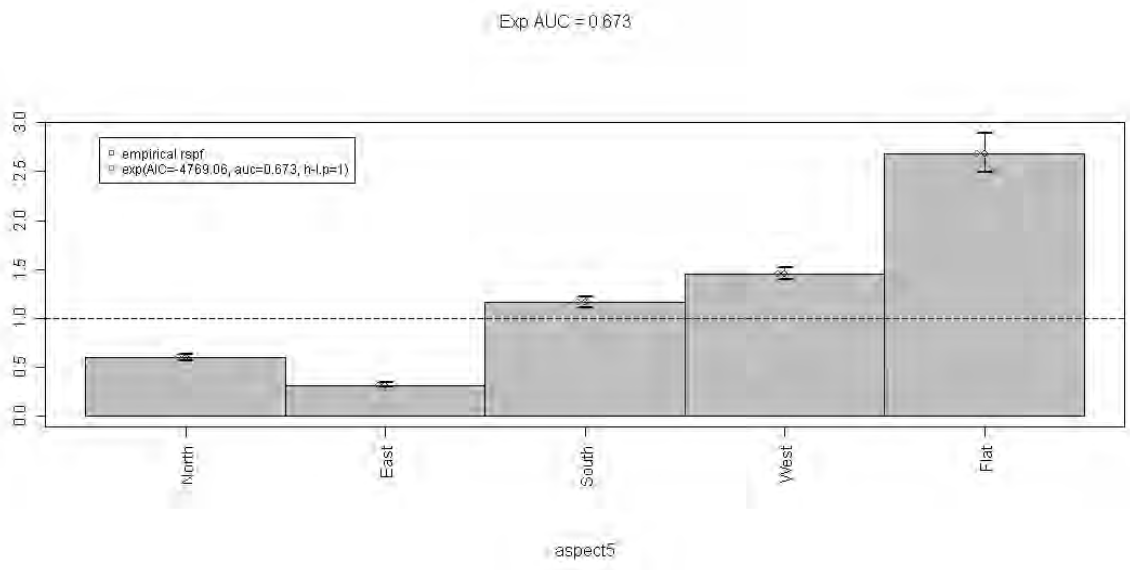
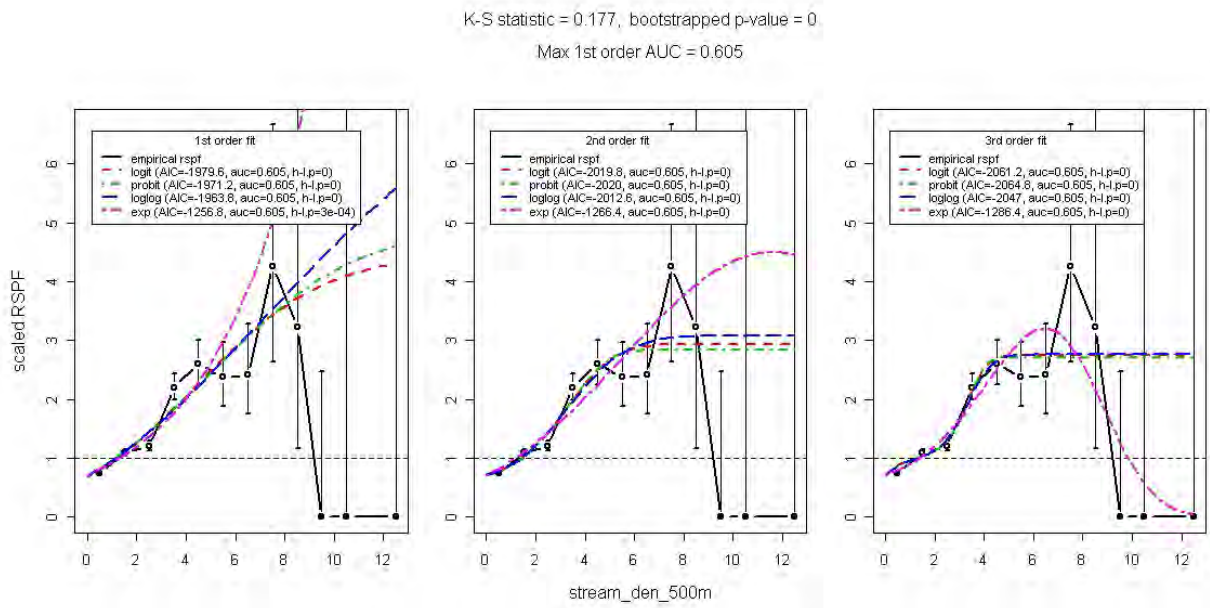


Figure 50. Tonquin caribou selection for stream density during the summer season (July 20th to September 26th) using the full final dataset (2002-2009).



3. Base Habitat Model

During the summer season, caribou selected exclusively for large patches of non-forested habitat and avoided all other vegetation classes. Several covariates were stronger predictors of habitat selection than the categorical "Veg5" covariate. Specifically, the coarse-scale non-forested class and patch size were the most important predictors of caribou habitat selection; however, they were strongly correlated, and the former was the better predictor retained for the model (Table 12).

Caribou selected predominantly for flat terrain between 2,000m and 2,500m in elevation (Figure 46) and south or west-facing slopes of up to 20 degrees (Figure 47). There was selection for areas up to within 5km of linear features (Figure 48). For the final model, the logit link provided the best fit to the data (Table 14) and average cross validated Spearman Rank Correlation was 0.92 (Table 15).

Table 12. Forward stepwise selection of covariates during the summer season (July 20st to September 26th) for Tonquin caribou (2002-2009). Covariates are listed left to right in order of their explanatory strength. The best model has the lowest AIC score and is bolded.

Model	Non forested 1km	Slope deg	DEM^2	Aspect5	Dist Linear	Stream Den 500m	AIC	AUC	Max VIF
1	X	X					-33806	0.909	1.2
2	X		X				-29728	0.895	1.4
3	X			X			-31932	0.902	1.8
4	X				X		-29140	0.892	1.3
5	X					X	-29298	0.894	1.1
6	X	X	X				-35873	0.919	1.9
7	X	X		X			-35025	0.912	1.8
8	X	X			X		-33860	0.910	1.5
9	X	X				X	-33848	0.910	1.4
10	X	X	X	X			-36993	0.922	2.0
11	X	X	X		X		-36140	0.920	2.2
12	X	X	X			X	-35880	0.919	2.0
13	**X**	**X**	**X**	**X**	**X**		**-37351**	**0.922**	**2.3**
14	X	X	X	X		X	-37065	0.922	2.0
15	X	X	X	X	X	X	-37209	0.922	2.4

Table 13. Coefficients and standard errors (SE) for Covariates in model 13 for the summer (July 20th to September 26th) season for Tonquin caribou (2002-2009).

Covariate	Estimate	SE	*t*	*p*	VIF
(Intercept)	-38.678	0.513	-86.04	<0.0001	NA
non forested 1km	4.848	0.162	39.96	<0.0001	2.3
Slope deg	-0.156	0.004	-51.36	<0.0001	2.0
DEM	31.094	0.463	32.71	<0.0001	1.6
DEM^2	-6.595	0.111	-23.05	<0.0001	1.2
aspect5East	-0.699	0.051	-14.37	<0.0001	1.5
aspect5South	0.416	0.046	6.06	<0.0001	1.7
aspect5West	0.810	0.040	18.88	<0.0001	1.8
aspect5Flat	0.029	0.057	4.22	<0.0001	1.8
Dist Linear km	-0.059	0.008	-18.68	<0.0001	1.3

Table 14. Fit statistics from model 13 with alternative link functions. The most parsimonious model is highlighted in bold.

Link	AIC	AUC	Max VIF
Logit	**-37351**	**0.922**	**2.3**
Loglog	-35478	0.921	2.3
Probit	-37011	0.922	2.3
Exponential	-37274	0.922	2.3

Table 15. Cross-validated Spearman-rank correlations (r_s) between RSF bin ranks and area-adjusted frequencies for individual and average model sets for Tonquin caribou during the summer (July 20th to September 26th) season (2002-2009).

Set	r_s	*P*
1	0.927	<0.0001
2	0.891	<0.0001
3	1.000	<0.0001
4	0.927	<0.0001
5	0.830	<0.0001
Average	0.915	<0.0001

4. Model Sensitivity

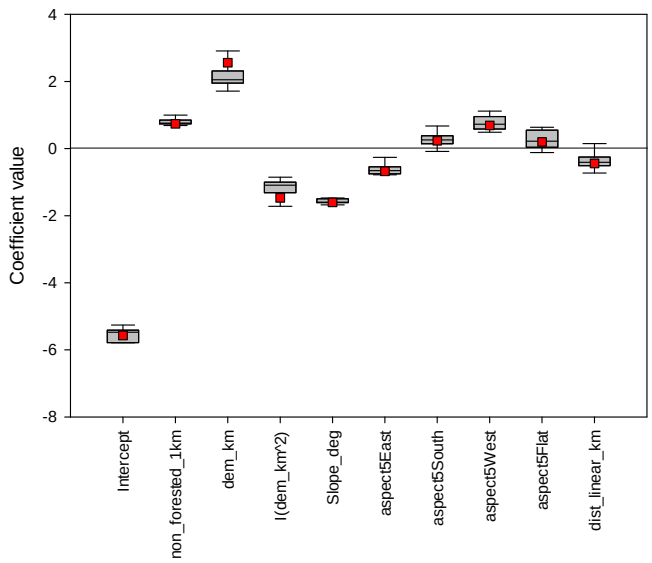
Generally, individual caribou selection patterns of final model covariates were remarkably consistent and well represented by the final model with representations of covariates using all available caribou data (Figures 45-50). Final model coefficient values were not significantly influenced by the behavior of individual caribou and no outliers were identified when individual caribou were excluded from model (Figure 51).

Individual caribou patterns for non-forested habitats clearly showed selection for areas with increasing proportion of this habitat type. Without exception, caribou selected elevations within the 2000m to 2500m described by the final model. Caribou selected for slopes of up to approximately 20 degrees. This is consistent with individual selection patterns of all caribou monitored.

In the final model, caribou selected primarily for flat terrain and then west or south-facing aspects. All caribou except for 41 selected primarily for flat terrain. Caribou were equally divided between greater

selection for south or west facing slopes. The larger coefficient for western exposure in the final model is a result of caribou with more locations exhibiting this behavioral pattern. Lastly, selection for distance to linear features at the individual scale was unclear.

Figure 51. Tonquin caribou sensitivity of standardized covariates during the summer season (July 20th to September 26th) using the full final dataset (2002-2009). Individual caribou were excluded sequentially and fit with the calving base model RSPF. Red squares represent full base model covariates.



Rut

1. Individual Caribou Habitat Selection Patterns

Caribou selected almost exclusively for non-forested alpine habitat during the summer season. Five of the 9 caribou monitored had data throughout the entire season, however, all caribou had sufficient data for individual exploratory analyses (Figure 52). All caribou selected exclusively for non-forested habitat and avoided all other habitat classes. Therefore, we considered individual caribou selection for general habitat types to be very similar and well represented by the global model (Figure 53) and chose to use all available caribou locations during the rutting season for model development.

Figure 52. Tonquin caribou locations during the rutting season (September 27th to October 31st) from 2002 to 2009.

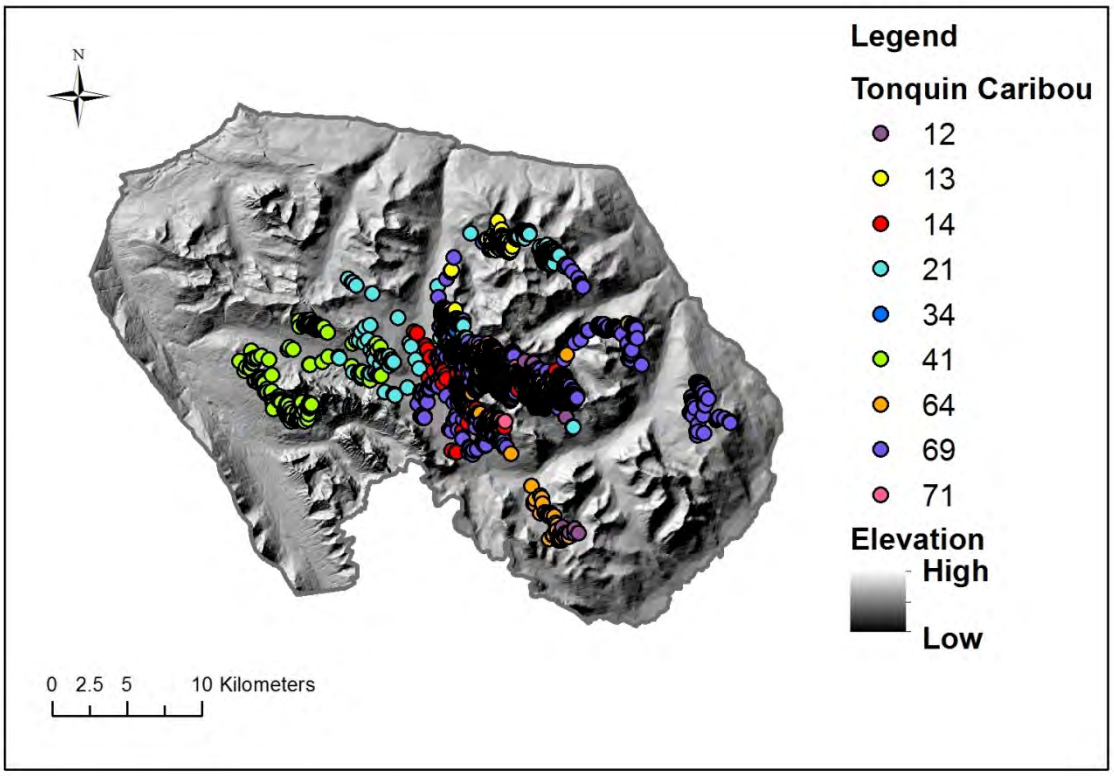
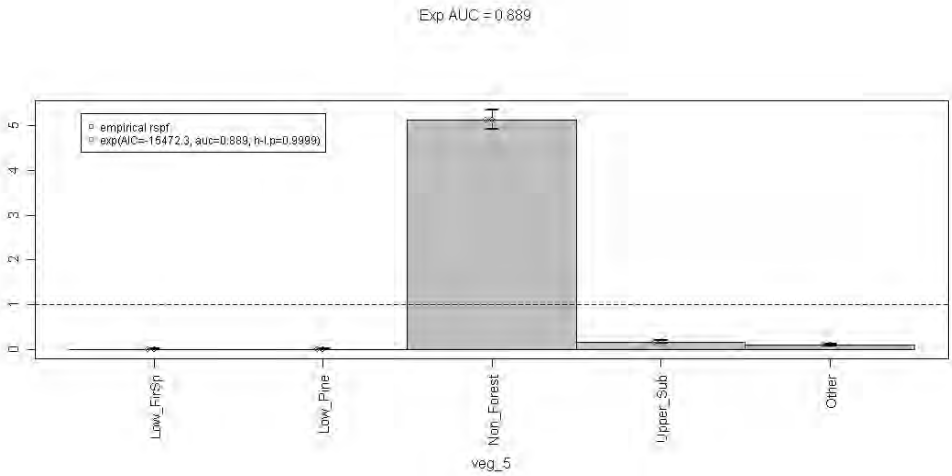


Figure 53. Tonquin caribou selection for habitat types during the rutting season (September 27th to October 31st) using the full final dataset (2002-2009).



2. Distributions of Potential Model Covariates

The logistic curve offered the best fit for most covariates and plots are presented below in order of best predictive values based on AIC scores (Figures 54 to 60). Caribou selected predominantly for large alpine patches and areas close to alpine habitat. Based on AIC scores, the loglog curve best fit the selection pattern of patch size (figure 54), however, all models except the exponential fit the data well. The logistic curve best fit the distance to alpine variable (Figure 55).The second order logistic curve best described caribou selection for mid-elevations (Figure 56).

Neither the first or second order slope models captured the pattern of selection between 0 and 10 degrees (Figure 57), however, this behavior is captured by the "flat" category in the aspect covariate (Figure 59). Therefore, we used the first order logistic to describe slope.

Figure 54. Tonquin caribou selection for alpine patch size during the rutting season (September 27th to October 31st) using the full final dataset (2002-2009).

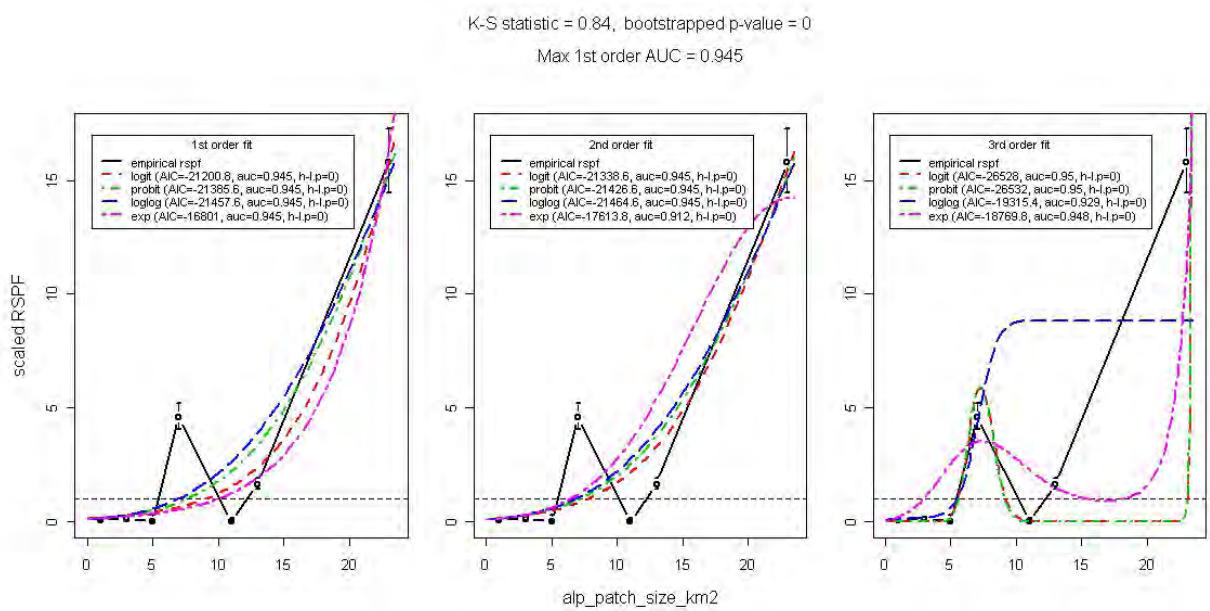


Figure 55. Tonquin caribou selection for the distance to alpine patch during the rutting season (September 27th to October 31st) using the full final dataset (2002-2009).

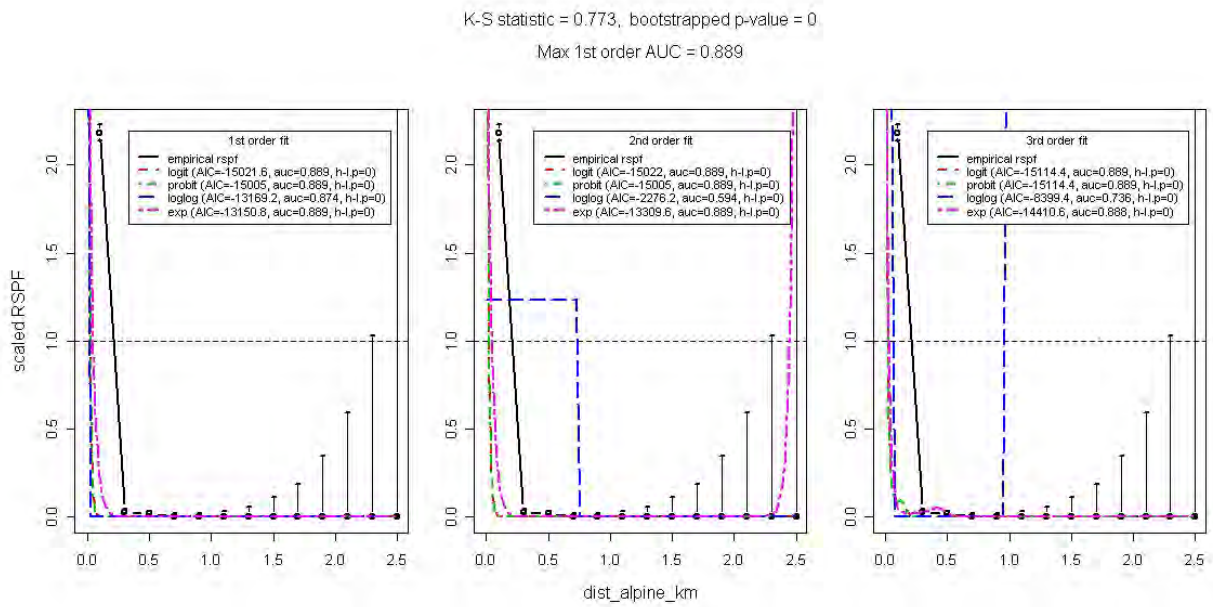


Figure 56. Tonquin caribou selection for elevation during the rutting season (September 27th to October 31st) using the full final dataset (2002-2009).

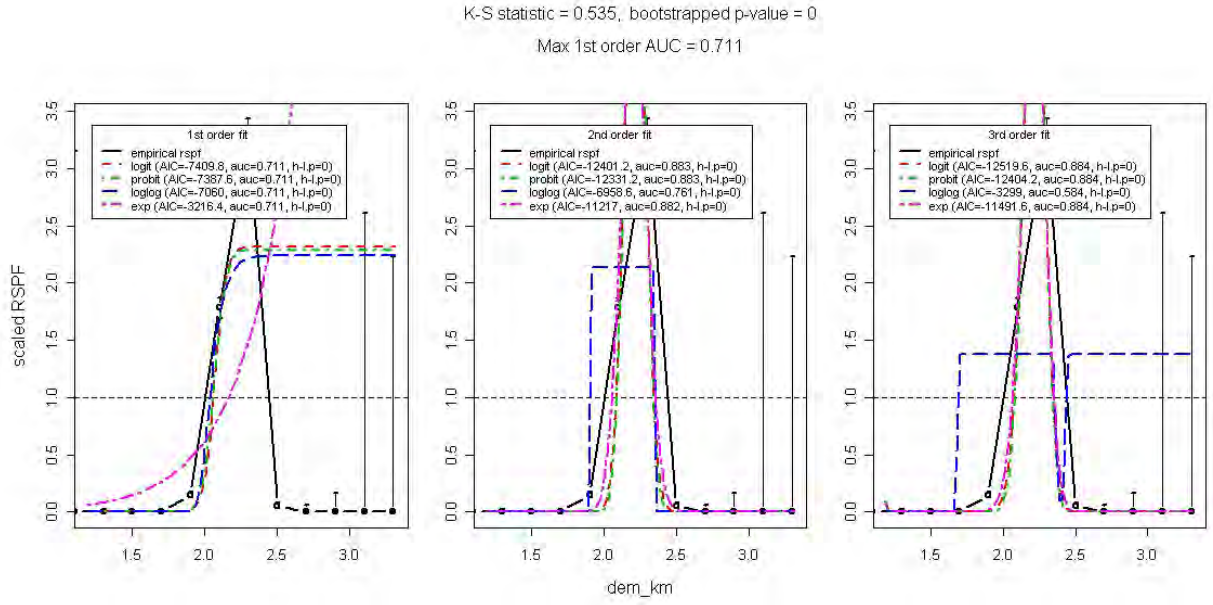


Figure 57. Tonquin caribou selection for slope during the rutting season (September 27th to October 31st) using the full final dataset (2002-2009).

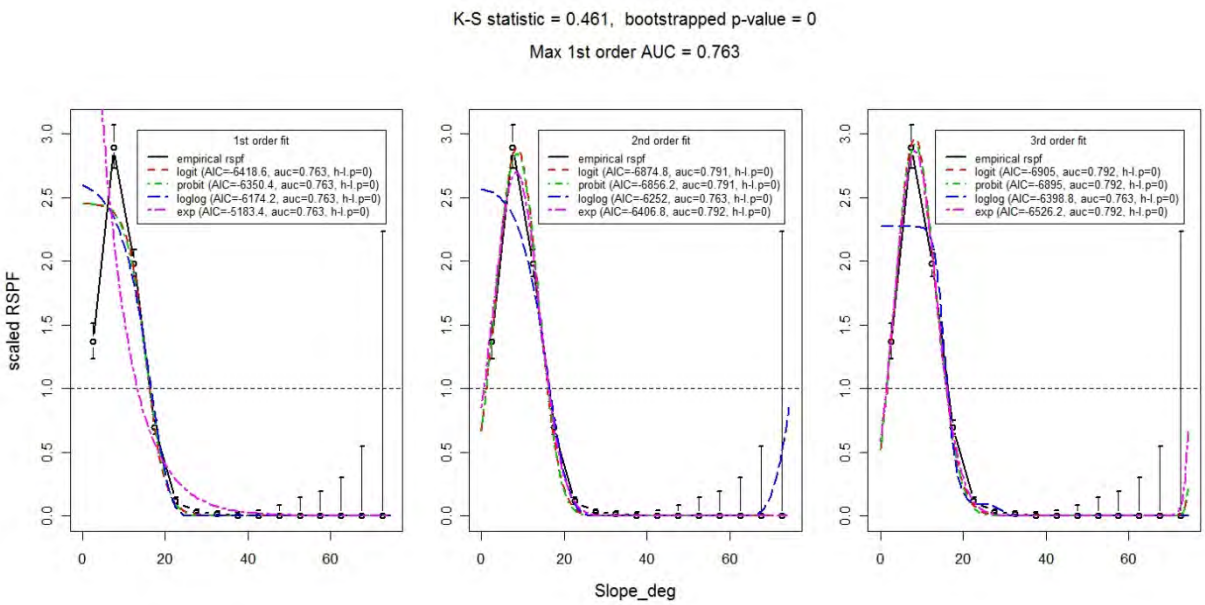


Figure 58. Tonquin caribou selection for the distance to linear features during the rutting season (September 27th to October 31st) using the full final dataset (2002-2009).

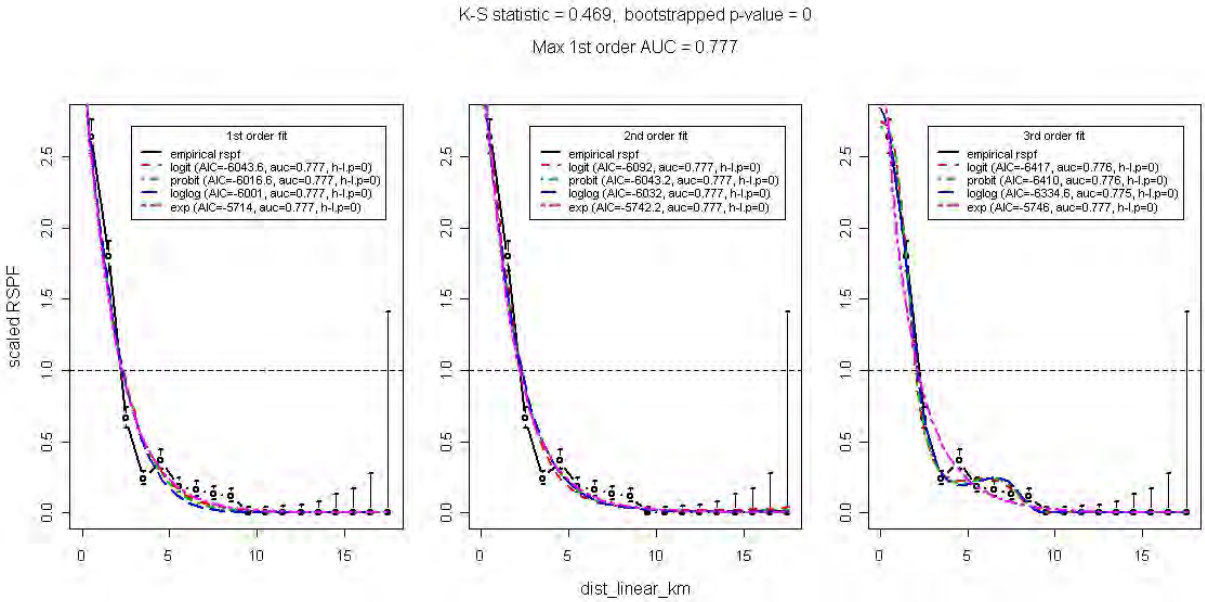


Figure 59. Tonquin caribou selection for aspect during the rutting season (September 27th to October 31st) using the full final dataset (2002-2009).

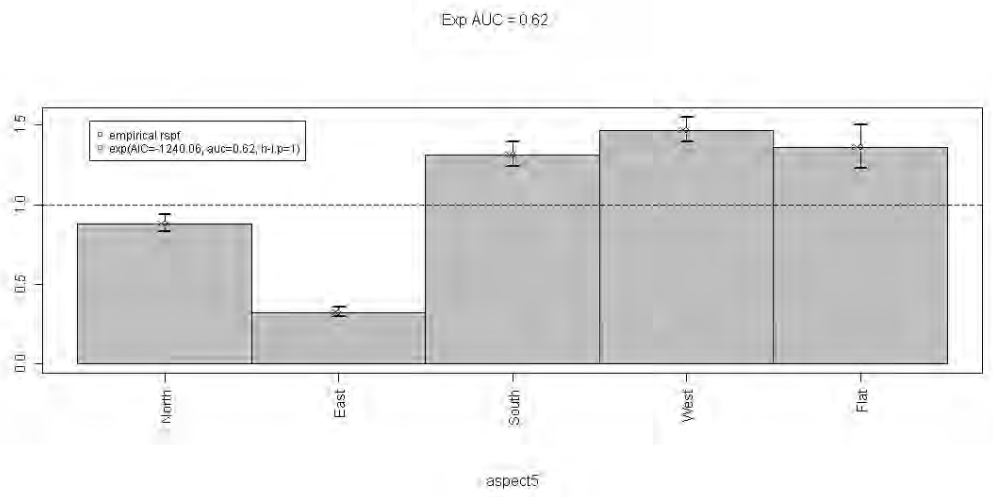
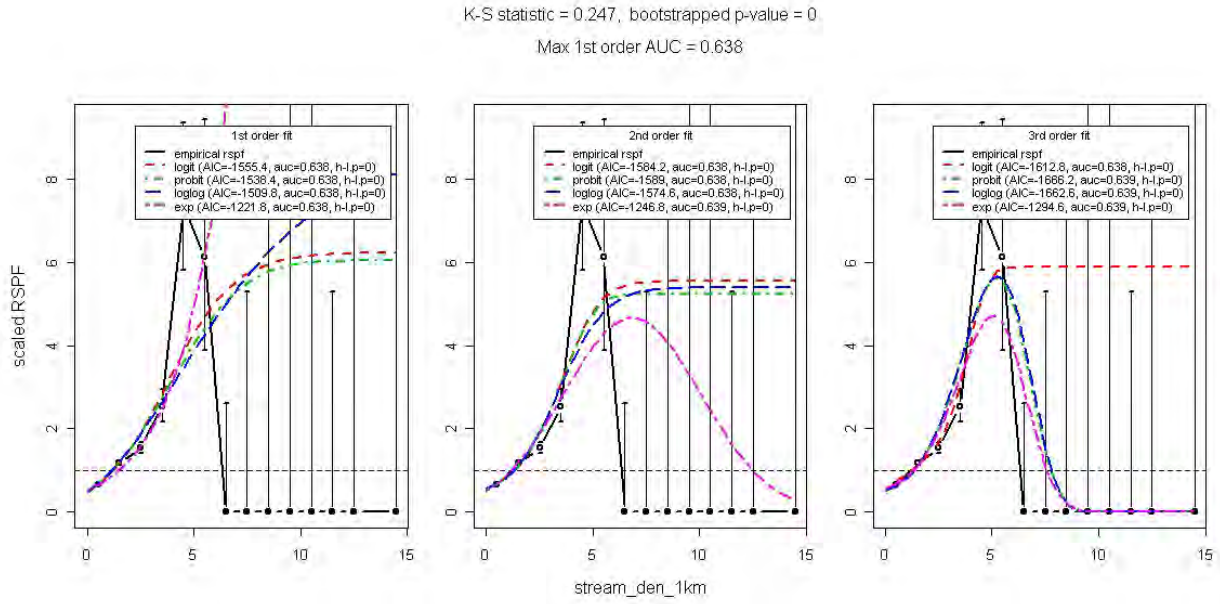


Figure 60. Tonquin caribou selection for stream density at the 1km scale during the rutting season (September 27th to October 31st) using the full final dataset (2002-2009).



3. Base Habitat Model

Caribou selected for large patches of non-forested habitat at elevations between 2,200 and 2,500m, with avoidance of all other habitat types. Caribou avoided east facing slopes but were just as likely to be on flat terrain or slopes of up to 20 degrees on other aspects. Lastly, they selected for areas close to linear features (Table 17). The exponential fit was slightly better than the logit fit when we tested the final model (difference of 34 in AIC scores but slightly lower value for AUC, Table 18). However, because when tested individually all variables were better fit with the logit link, we retained the logistic for the final model. The average cross validated Spearman Rank Correlation was 0.87 (Table 19).

Table 16. Forward stepwise selection of covariates during the rutting season (September 27th to October 31st) for Tonquin caribou (2002-2009). Covariates are listed left to right in order of their explanatory strength. The best model has the lowest AIC score and is bolded.

Model	Patch Size	Dist linear km	DEM^2	Slope deg	Aspect	Dist Patch	Stream Den 1km	AIC	AUC	Max VIF
1	X	X						-24181	0.937	1.2
2	X		X					-23515	0.949	1.2
3	X			X				-22200	0.943	1.2
4	X				X			-22134	0.934	1.6
5	X					X		-22459	0.962	1.3
6	X						X	-21268	0.933	1.1
7	X	X	X					-26708	0.958	1.4
8	X	X		X				-24689	0.944	1.4
9	X	X			X			-25279	0.940	1.6
10	X	X				X		-25240	0.955	1.5
11	X	X					X	-24182	0.937	1.3
12	X	X	X	X				-28188	0.965	1.8
13	X	X	X		X			-27603	0.959	1.6
14	X	X	X			X		-27193	0.964	1.9
15	X	X	X				X	-26793	0.957	1.6
16	X	X	X	X	X			-29041	0.967	1.8
17	X	X	X	X		X		-28426	0.967	1.9
18	X	X	X	X			X	-28168	0.965	1.9
19	**X**	**X**	**X**	**X**	**X**	**X**		**-29212**	**0.968**	**2.0**
20	X	X	X	X	X		X	-28859	0.966	2.0
21	X	X	X	X	X	X	X	-29216	0.968	2.0

Table 17. Coefficients and standard errors (SE) for Covariates in model 5 for the rutting (September 27th to October 31st) season for Tonquin caribou (2002-2009).

Covariate	Estimate	SE	*Z value*	*p*	VIF
(Intercept)	-126.607	3.540	-35.76	<0.0001	NA
Patch Size	0.098	0.004	23.50	<0.0001	1.90
dist linear	-0.430	0.027	-15.72	<0.0001	1.50
DEM	112.389	3.418	32.88	<0.0001	1.60
DEM^2	-25.374	0.862	-29.44	<0.0001	1.30
Slope deg	-0.105	0.011	-9.60	<0.0001	1.80
aspect5East	-1.237	0.324	-3.81	<0.0001	1.50
aspect5South	-0.392	0.153	-2.57	0.0102	1.60
aspect5West	0.152	0.129	1.18	<0.0001	1.60
aspect5Flat	-1.146	0.278	-4.12	<0.0001	1.50
Dist Patch	-7.486	1.088	-6.88	<0.0001	2.00

Table 18. Fit statistics from model 19 during the rutting season (September 27th to October 31st) for Tonquin caribou (2002-2009) with alternative link functions. The most parsimonious model is highlighted in bold.

Link	AIC	AUC	Max VIF
Logit	-29212	0.968	2.0
Loglog	NA	NA	NA
Probit	-28929	0.969	2.0
Exponential	**-29246**	**0.969**	**2.0**

Table 19. Cross-validated Spearman-rank correlations (r_s) between RSF bin ranks and area-adjusted frequencies for individual and average model sets for Tonquin caribou during the rutting season (September 27th to October 31st) season (2002-2009).

Set	r_s	*P*
1	0.903	<0.0001
2	0.782	0.008
3	0.927	<0.0001
4	0.851	0.002
5	0.867	0.001
Average	0.866	0.003

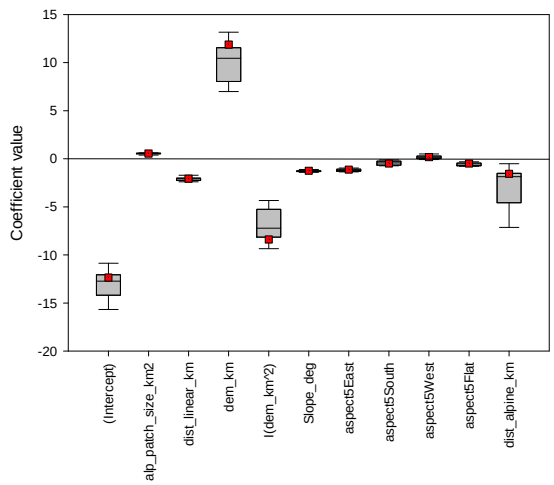
4. Model Sensitivity

Generally, individual caribou selection patterns were relatively consistent and well represented by the final model with representations of covariates using all available caribou data (Figures 54-60). Individual caribou selection for patch size was consistent with the final model where caribou selection increased for larger patches. Similarly, all caribou selected for areas closer to linear features and alpine patches, although the strength of selection was highly variable between individuals which is probably a result of varying sample sizes.

Without exception, caribou selected elevations within the 2000m to 2500m described by the final model. Figure 61 shows greater inter-caribou variation for elevation than other covariates. This is a result of variations in the shape of the selection curve for individual caribou. However, because all caribou selected for elevations described by the final model, we believe the base model is an accurate representation of the mean curve shape.

Selection for slope and aspect was variable between individuals, however, all caribou avoided east-facing slopes and this is well described by the final model. Generally, caribou selected first for south and/or west-facing slopes of approximately 10 degrees and then for flat terrain. There were no caribou that significantly affected covariate values (Figure 61).

Figure 61. Tonquin caribou sensitivity of standardized covariates during the rutting season (September 27th to October 31st) using the full final dataset (2002-2009). Individual caribou were excluded sequentially and fit with the calving base model RSPF. Red squares represent full base model covariates.



Early Winter

1. Individual Caribou Habitat Selection Patterns

Individual caribou exhibited variable habitat selection patterns such that differences in locations/animal would have biased coefficients. The dataset was reduced to 14,371 locations to minimize bias of animals selecting for a particular habitat type (see section 6.1.3.1 for details).

Selection for specific habitat types did not appear to be spatially distributed within the Tonquin Range (Figure 62) suggesting that the source of variation could be animal specific or a result of annual climatic variation. Unfortunately, the number of animals sampled annually do not allow for an accurate assessment of an effect of the year monitored. Regardless, because our goal is prediction and not hypothesis testing, these models are to represent and incorporate the range of variation within the season. As such, we consider the veg_5 covariate with the reduced data (Figure 63) an accurate estimated representation of behaviors observed over 8 years of monitoring.

Figure 62. Tonquin caribou locations during the early winter season (November 1st to January 21st) from 2002 to 2009.

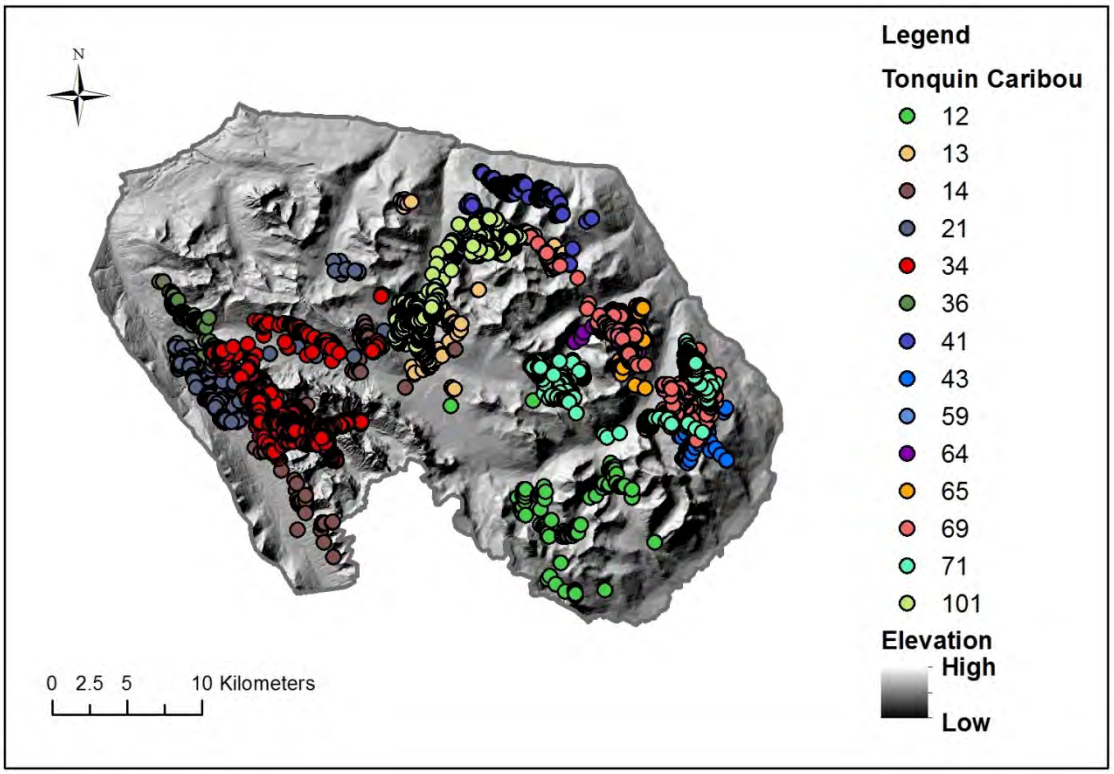
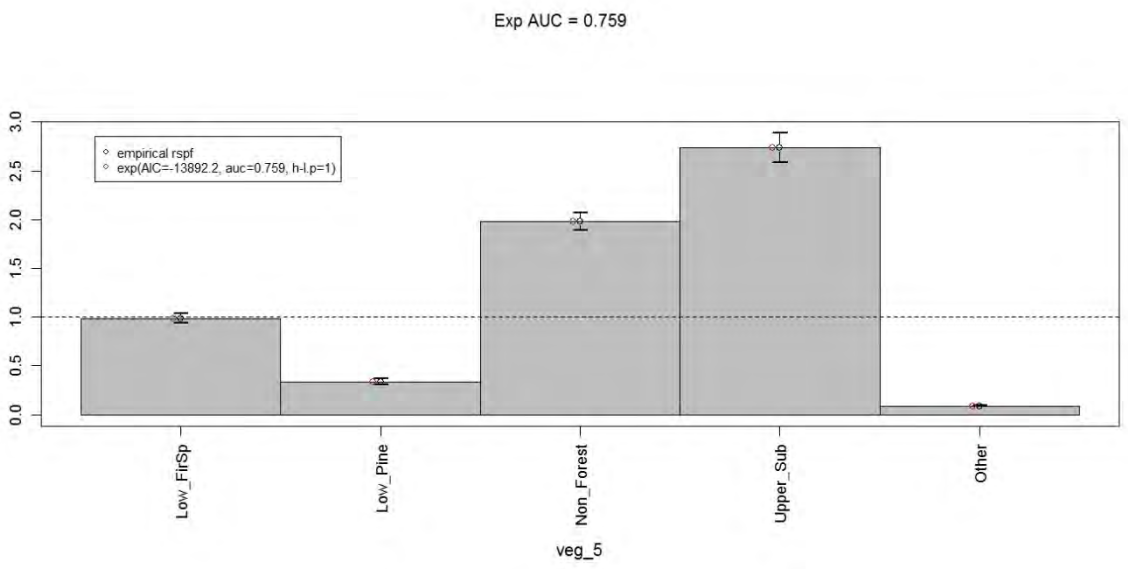


Figure 63. Tonquin caribou selection for habitat types during the early winter season (November 1st to January 21st) using the full final dataset (2002-2009).



2. Distributions of Potential Model Covariates

Few covariates had clear selection patterns during the early winter season. Elevation was the strongest predictor after the veg-5 covariate and was best predicted by the second order loglog curve but all models had relatively good fit (Figure 64). Slope and terrain ruggedness were best predicted by the first order logistic curve (Figures 65 and 67).

Figure 64. Tonquin caribou selection for elevation during the early winter season (November 1st to January 21st) using the full final dataset (2002-2009).

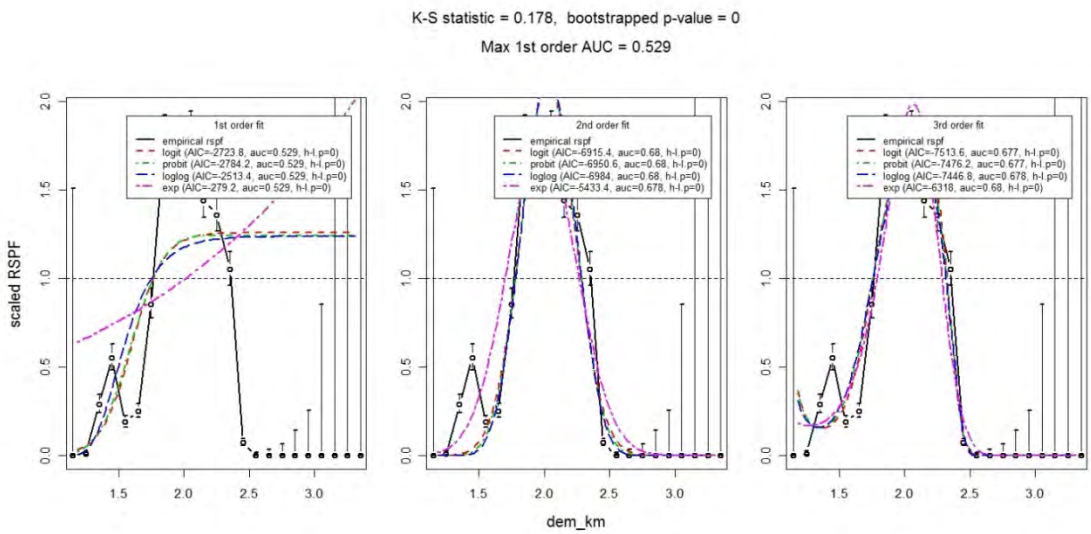


Figure 65. Tonquin caribou selection for slope during the early winter season (November 1st to January 21st) using the full final dataset (2002-2009).

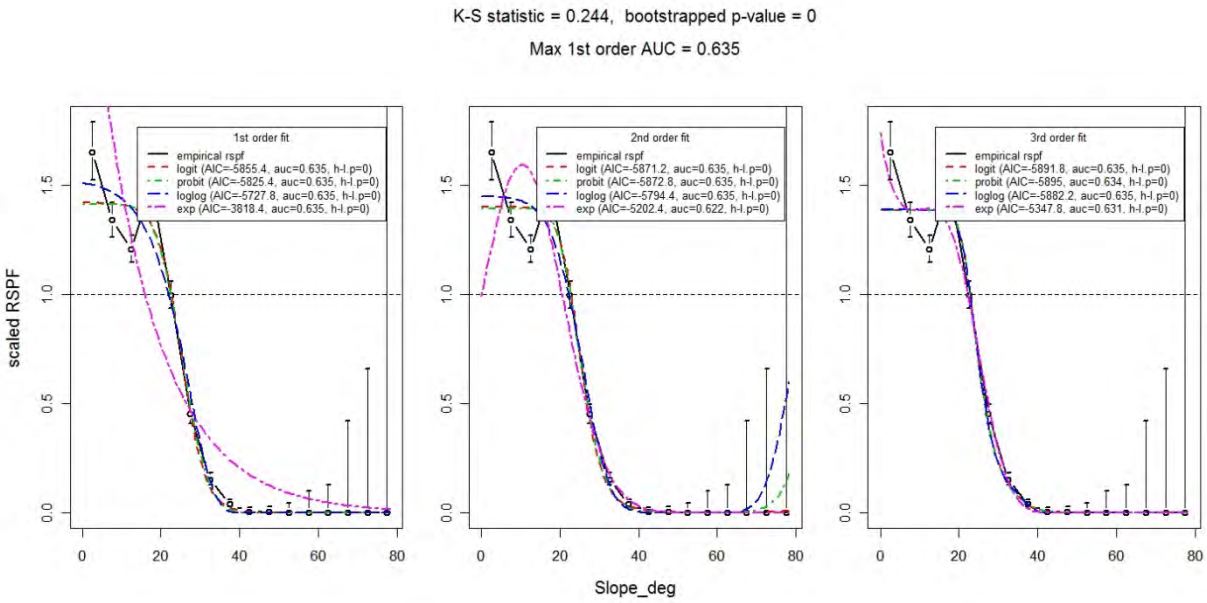


Figure 66. Tonquin caribou selection for aspect during the early winter season (November 1st to January 21st) using the full final dataset (2002-2009).

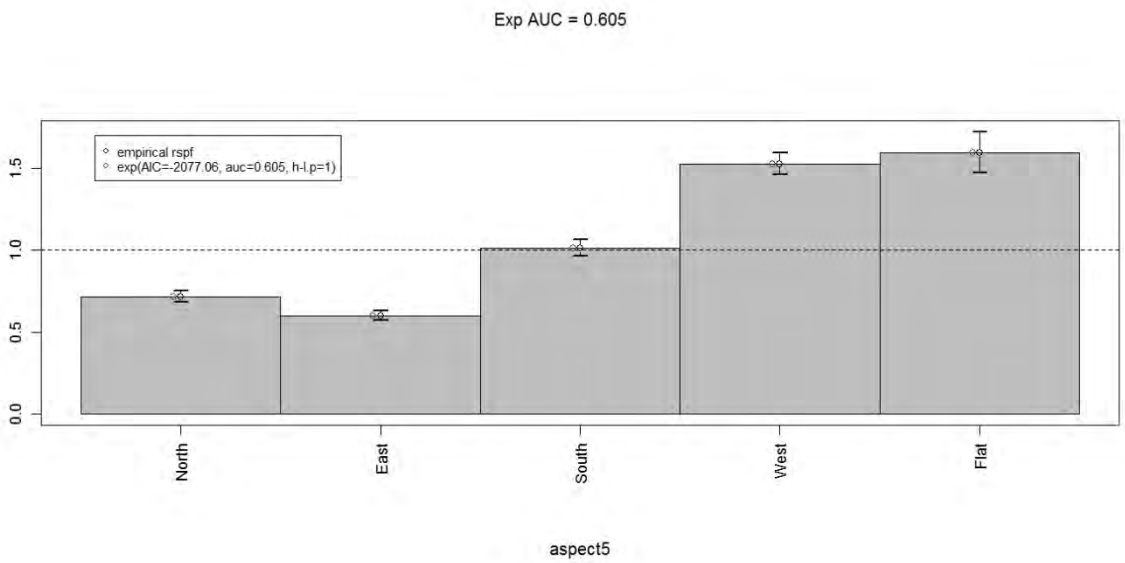
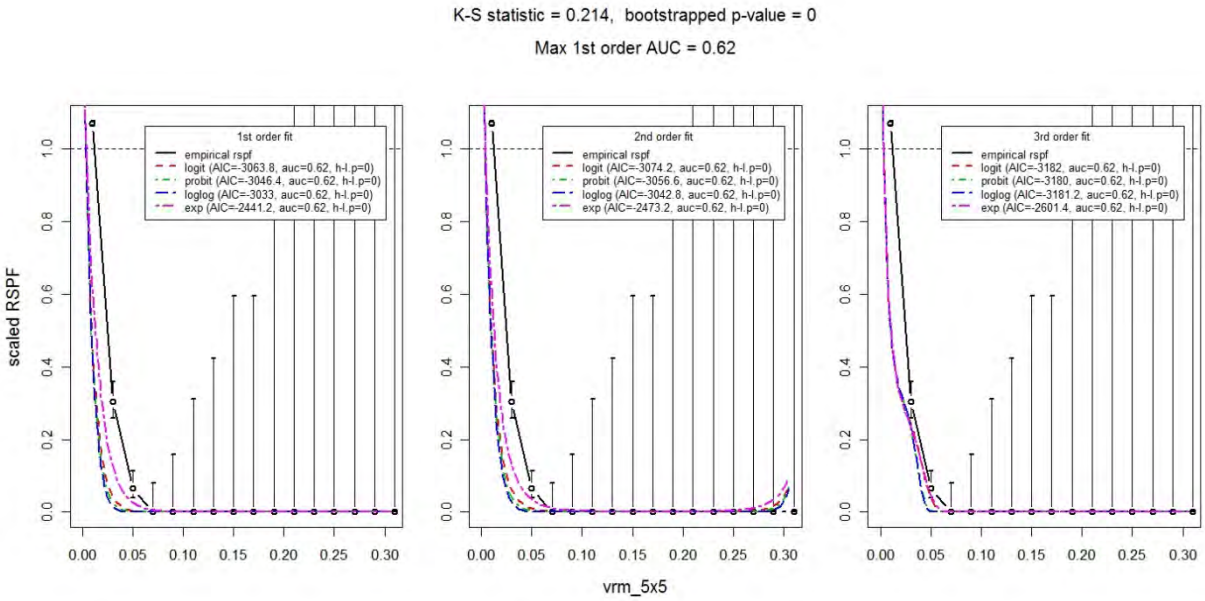


Figure 67. Tonquin caribou selection for terrain ruggedness during the early winter season (November 1st to January 21st) using the full final dataset (2002-2009).



3. Base Habitat Model

Early winter habitat selection was best predicted by the full model that included the categorical variable of all vegetation/landscape classes (Veg_5). Caribou selected for elevations between 1,800m and 2,200m and demonstrated greater selection for lower elevations within this range. However, elevation was excluded from the model because it was highly correlated to *Veg_5*. Caribou selected primarily for 200 year old upper subalpine forest, secondly for non-forested habitat (with no selection for patch size), and selected for both lower subalpine classes equal to availability. Lastly, caribou selected first for flat terrain and then for west facing slopes of up to 30 degrees. The inclusion of terrain ruggedness in the model did not significantly increase model fit (Table 20). The logit link provided the best fit to the data (Table 22) and average cross validated Spearman Rank Correlation was 0.98 (Table 23).

Table 20. Forward stepwise selection of covariates during the early winter season (November 1st to January 21st) for Tonquin caribou (2002-2009). Covariates are listed left to right in order of their explanatory strength. The best model has the lowest AIC score and is bolded.

Model	Veg 5	Slope deg	Aspect5	VRM	AIC	AUC	Max VIF
1	X	X			-15381	0.775	1.7
2	X		X		NA	NA	NA
3	X			X	-14116	0.766	1.7
4	**X**	**X**	**X**		**-16339**	**0.784**	**1.7**
5	X	X		X	-15386	0.775	1.7
6	X	X	X	X	-16343	0.784	1.8

Table 21. Coefficients and standard errors (SE) for Covariates in model 4 for the early winter (November 1st to January 21st) season for Tonquin caribou (2002-2009).

Covariate	Estimate	SE	*Z value*	*p*	VIF
(Intercept)	-0.019	0.140	-0.14	0.8902	NA
Veg5 Low Pine	-1.203	0.069	-17.51	<0.0001	1.3
Veg5 Non Forest	1.373	0.083	16.44	<0.0001	1.7
Veg5Upper Sub	2.068	0.144	14.33	<0.0001	1.7
Veg5 Other	-2.278	0.064	-35.33	<0.0001	1.7
Slope deg	-0.078	0.005	-16.91	<0.0001	1.6
aspect5East	-0.548	0.062	-8.86	<0.0001	1.6
aspect5South	0.295	0.098	3.02	0.0026	1.6
aspect5West	0.889	0.055	16.31	<0.0001	1.7
aspect5Flat	-0.202	0.094	-2.16	0.0310	1.7

Table 22. Fit statistics from model 4 during the early winter season (November 1st to January 21st) for Tonquin caribou (2002-2009) with alternative link functions. The most parsimonious model is highlighted in bold.

Link	AIC	AUC	Max VIF
Logit	**-16339**	**0.784**	**1.7**
Loglog	-15573	0.770	1.7
Probit	-16346	0.784	1.7
Exponential	-16020	0.784	1.7

Table 23. Cross-validated Spearman-rank correlations (r_s) between RSF bin ranks and area-adjusted frequencies for individual and average model sets for Tonquin caribou during the early winter (November 1st to January 21st) season (2002-2009).

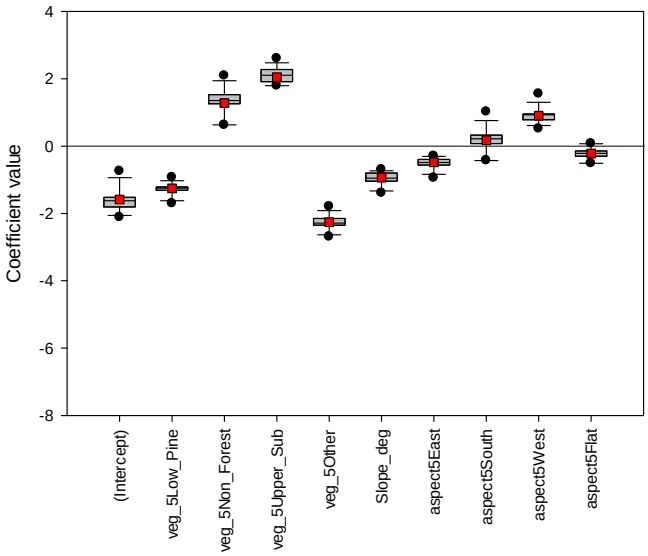
Set	r_s	*P*
1	0.976	<0.0001
2	0.988	<0.0001
3	0.964	<0.0001
4	0.976	<0.0001
5	0.964	<0.0001
Average	0.973	<0.0001

4. Model Sensitivity

Generally, individual caribou selection patterns of final model covariates were more variable than during the snow-free period. In addition, several caribou were identified as outliers in the sensitivity analysis (Figure 68), however, final model coefficients represented mean values well and were not influenced by these extreme values.

Three (animals 41, 64, 65) of the 14 caribou monitored during the early winter avoided flat terrain whereas remaining caribou with sufficient data to identify a pattern selected primarily for slopes of 20 degrees. Individual caribou selection for aspects also was variable. All caribou except for 41, 59, and 71 selected for west and/or south facing slopes and this is well represented by the final global model. These 3 caribou were the only animals that did not avoid north and east facing slopes.

Figure 68. Tonquin caribou sensitivity of standardized covariates during the early winter season (November 1st to January 21st) using the full final dataset (2002-2009). Individual caribou were excluded sequentially and fit with the calving base model RSPF. Red squares represent full base model covariates.



Late Winter

1. Individual Caribou Habitat Selection Patterns

Individual caribou exhibited variable habitat selection patterns such that differences in locations/animal would have biased coefficients. The dataset was reduced to 22,708 locations to minimize bias resulting from unequal sample sizes between caribou (see section 6.1.3.1 for details).

Twelve of the 13 caribou monitored had sufficient data for individual exploratory analyses (Figure 69). Individual selection for habitat types was variable between individuals and the only consistent pattern was the avoidance of the 'other' class. Because caribou exhibited various selection patterns within a given year, we believe the global model with the reduced dataset is an accurate representation of the overall selection patterns observed during the late winter season.

Figure 69. Tonquin caribou locations during the late winter season (January 22nd to May 22nd) from 2002 to 2009.

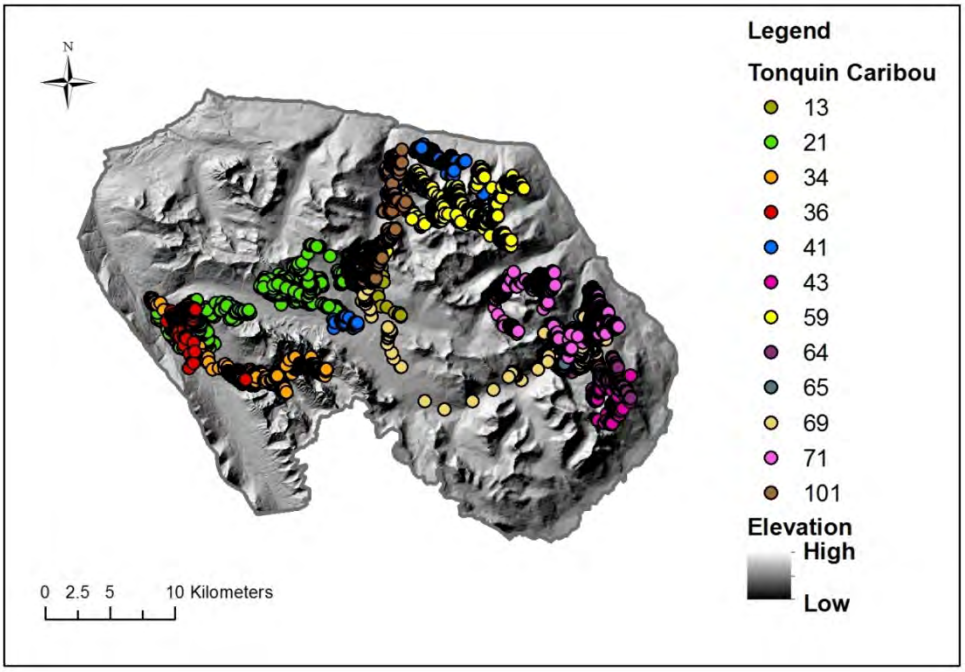
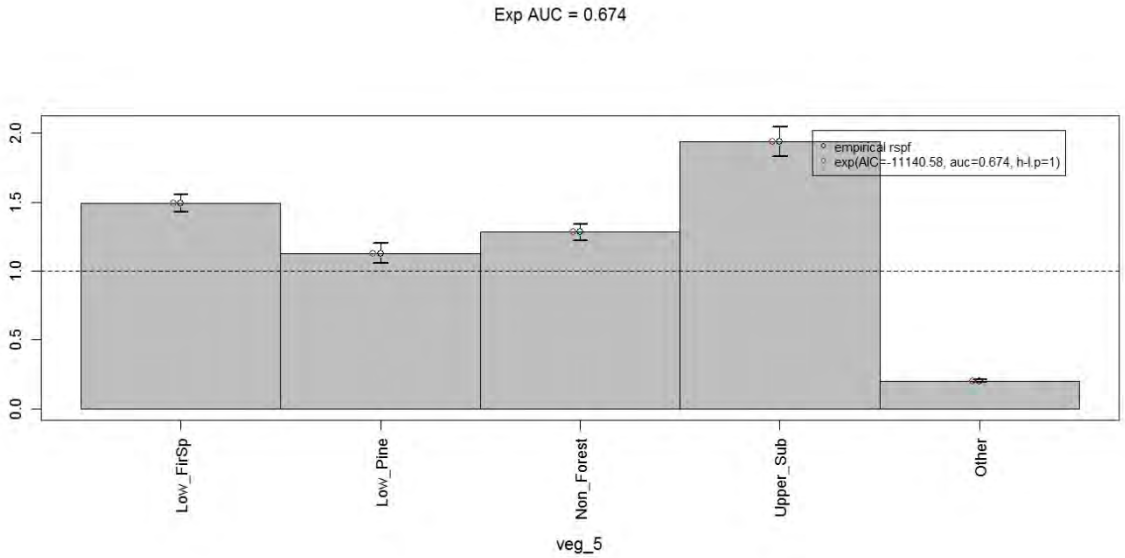


Figure 70. Tonquin caribou selection for habitat types during the late winter (January 22nd to May 22nd) season using the full final dataset (2002-2009).



2. Distributions of Potential Model Covariates

Few covariates had clear selection patterns during the late winter season. Elevation was the strongest predictor after the veg-5 covariate and was best modeled by the second order logit curve (Figure 71). Slope was best described by the second order probit curve (Figure 72) because no first order model captured selection at the lower end of the scale.

Figure 71. Tonquin caribou selection for elevation during the late winter (January 22nd to May 22nd) season using the full final dataset (2002-2009).

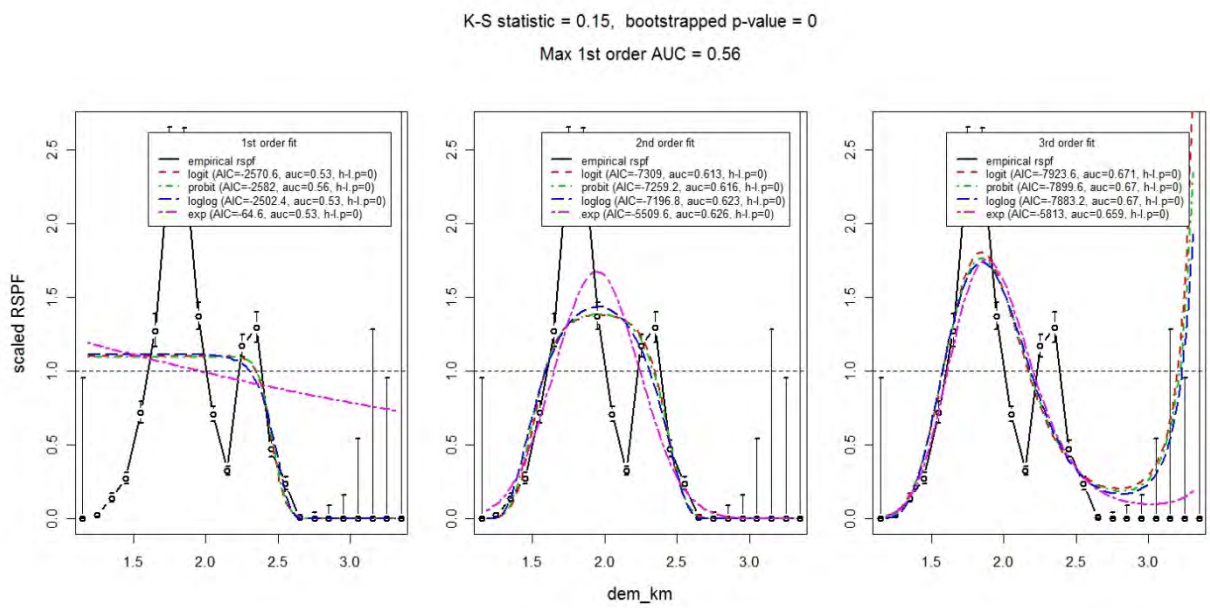


Figure 72. Tonquin caribou selection for slope during the late winter (January 22nd to May 22nd) season using the full final dataset (2002-2009).

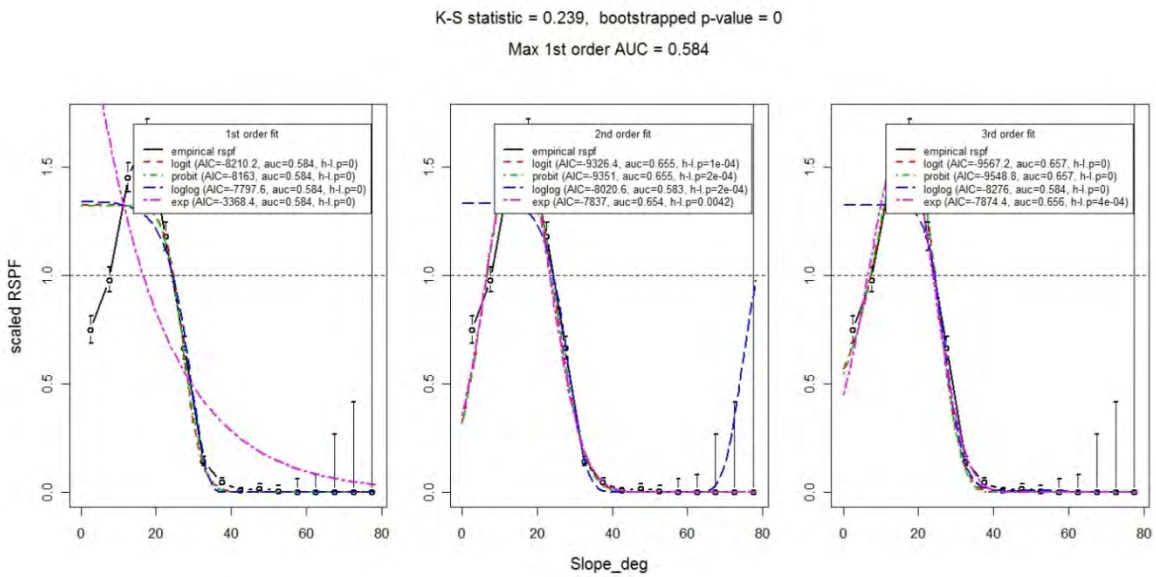
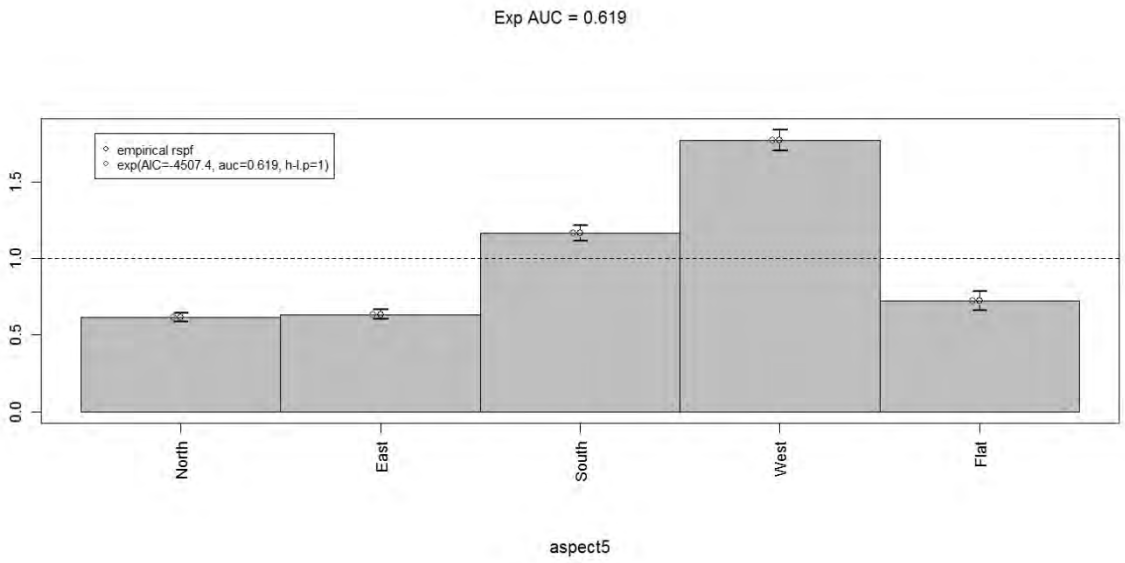


Figure 73. Tonquin caribou selection for aspect during the late winter (January 22nd to May 22nd) season using the full final dataset (2002-2009).



3. Base Habitat Model

Similar to the early winter season, late winter habitat selection was best predicted by the full model that included the categorical variable of all vegetation/landscape classes (Veg_5). However, caribou were more dispersed across various vegetation/landscape types than during other seasons. Caribou demonstrated selection for all vegetation classes and avoided only the *other* class which consists primarily of rock/ice and waterbodies. Selection was greatest for the upper subalpine class and then similar for the remaining 3 vegetation types. Caribou selected most for west facing slopes of up to 30 degrees. Flat terrain was avoided and slope was best described with a second order transformation; however, we used the first order fit because this information was contained in the flat level of the *Aspect5* covariate(Table 25). The exponential link provided the best fit to the data (Table 26), however, the logit link provided a better biological fit and was retained as the final model. Specifically, the exponential link provided a good fit to the slope data at higher slope values but overestimated selection at lower slopes because of the shape of the function. The average cross validated Spearman Rank Correlation was 0.98 (Table 27).

Table 24. Forward stepwise selection of covariates during the late winter season (January 22nd to May 22nd) for Tonquin caribou (2002-2009). Covariates are listed left to right in order of their explanatory strength. The best model has the lowest AIC score and is bolded.

Model	Veg 5	Slope deg	Aspect5	AIC	AUC	Max VIF
1	X	X		-12815	0.668	1.4
2	X		X	NA	NA	NA
3	**X**	**X**	**X**	-16280	0.725	2.0

Table 25. Coefficients and standard errors (SE) for Covariates in model 3 for the late winter (January 22nd to May 22nd) season for Tonquin caribou (2002-2009).

Covariate	Estimate	SE	*Z value*	*p*	VIF
(Intercept)	1.189	0.184	6.45	<0.0001	NA
Veg5 Low Pine	-0.192	0.054	-3.55	0.0004	1.3
Veg5 Non Forest	-0.346	0.049	-7.02	<0.0001	1.5
Veg5 Upper Sub	1.128	0.115	9.80	<0.0001	1.4
Veg5 Other	-2.461	0.063	-39.17	<0.0001	1.5
Slope deg	-0.087	0.005	-17.85	<0.0001	1.3
aspect5East	-0.323	0.066	-4.88	<0.0001	1.7
aspect5South	1.503	0.091	16.49	<0.0001	1.9

aspect5West	1.688	0.050	34.08	<0.0001	2.0
aspect5Flat	-1.329	0.103	-12.95	<0.0001	1.5

Table 26. Fit statistics from model 3 during the early late season (January 22nd to May 22nd) for Tonquin caribou (2002-2009) with alternative link functions. The most parsimonious model is highlighted in bold.

Link	AIC	AUC	Max VIF
Logit	**-16280**	**0.725**	**2**
Loglog	-16159	0.726	2
Probit	-16094	0.724	2
Exponential	-15900	0.729	2

Table 27. Cross-validated Spearman-rank correlations (r_s) between RSF bin ranks and area-adjusted frequencies for individual and average model sets for Tonquin caribou during the late winter (January 22nd to May 22nd) season (2002-2009).

Set	r_s	*P*
1	0.976	<0.0001
2	0.964	<0.0001
3	0.927	<0.0001
4	0.842	<0.0001
5	0.939	<0.0001
Average	0.930	<0.0001

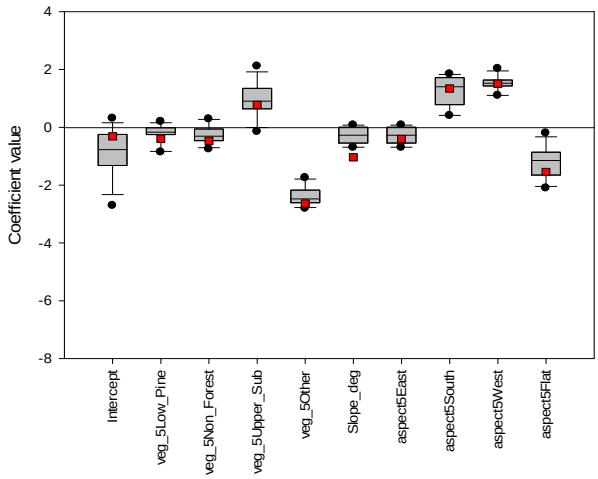
4. Model Sensitivity

Generally, individual caribou selection patterns were well represented by the final model but individuals did exhibit a high degree of variation. All individuals except 2 caribou (34 and 64) selected primarily for slopes of approximately 20 degrees and avoided flat terrain. These 2 outliers also selected primarily for slopes of 20 degrees but showed selection for flat terrain. These caribou ranged over non-overlapping areas (Figure 69) and were monitored in different years.

Generally, caribou selected for south and/or west facing slopes, however, there was significant variation in selection patterns between individuals. Only two (caribou 41 and 65) of the 14 caribou monitored showed selection for north facing slopes. This general pattern is well represented by the final model and the individual variation is visible in the sensitivity analysis where the range of coefficient values varies

significantly with sequential removal of individual caribou (Figure 74). There was no clear spatial or temporal correlation for observed selection patterns. All model coefficients except slope fall within the mean range of coefficient values.

Figure 74. Tonquin caribou sensitivity of standardized covariates during the early winter (November 1st to January 21st) using the full final dataset (2002-2009). Individual caribou were excluded sequentially and fit with the calving base model RSPF. Red squares represent full base model covariates.



6.2 Seasonal Individual Caribou Selection for General Habitat Types

Calving

Figure 75. Tonquin caribou 21 selection for covariate Veg_5 during the calving season (May 23rd to June 20th) using the full final dataset (2002-2009).

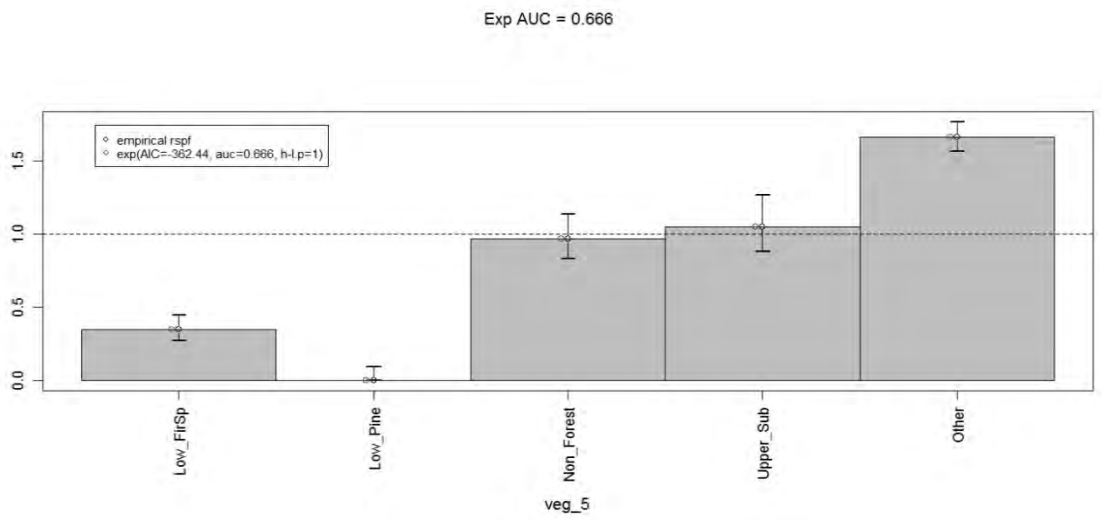


Figure 76. Tonquin caribou 34 selection for covariate Veg_5 during the calving season (May 23rd to June 20th) using the full final dataset (2002-2009).

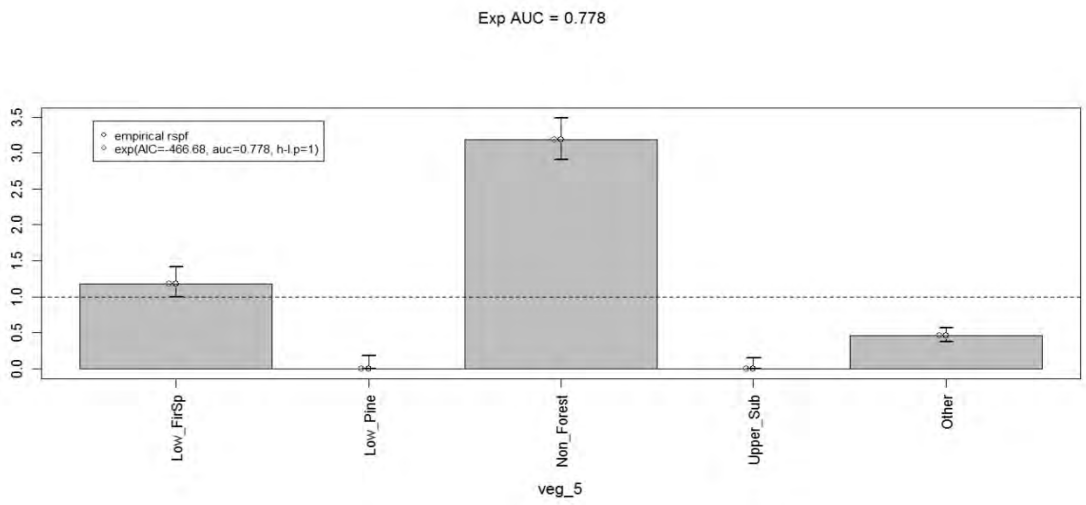


Figure 77. Tonquin caribou 41 selection for covariate Veg_5 during the calving season (May 23rd to June 20th) using the full final dataset (2002-2009).

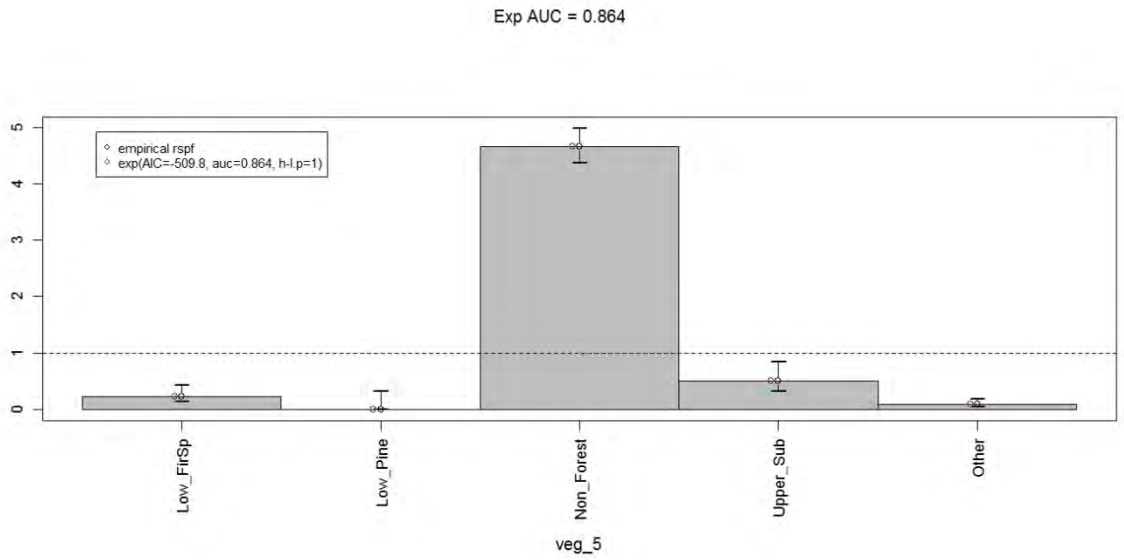


Figure 78. Tonquin caribou 59 selection for covariate Veg_5 during the calving season (May 23rd to June 20th) using the full final dataset (2002-2009).

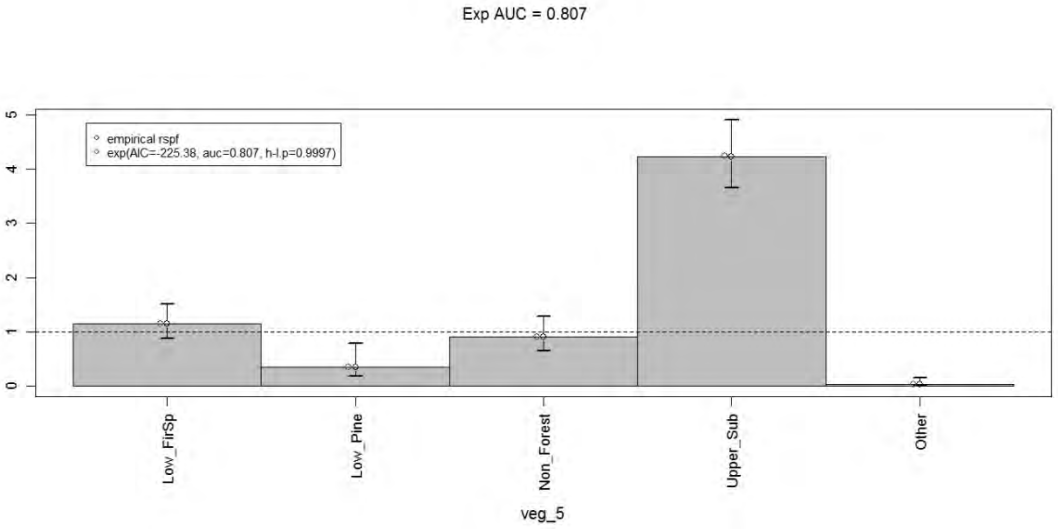


Figure 79. Tonquin caribou 64 selection for covariate Veg_5 during the calving season (May 23rd to June 20th) using the full final dataset (2002-2009).

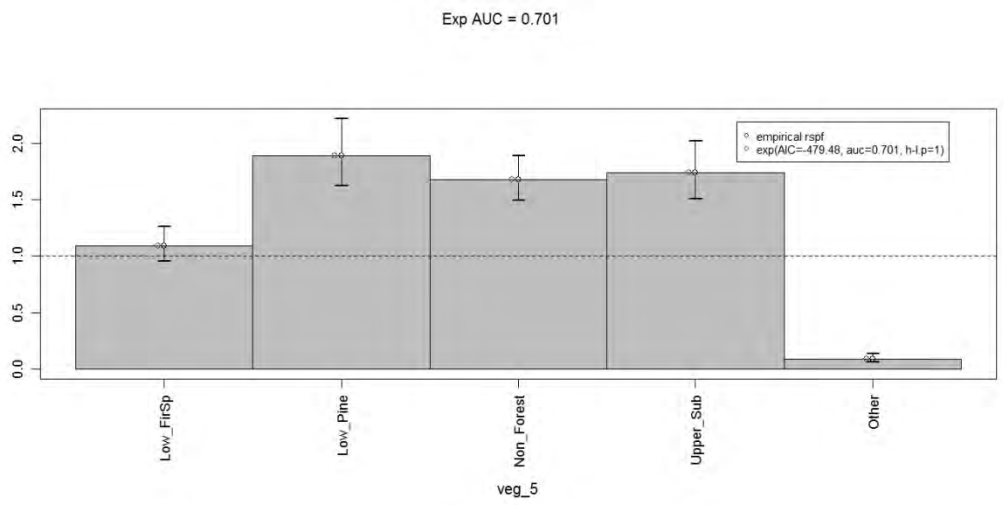


Figure 80. Tonquin caribou 69 selection for covariate Veg_5 during the calving season (May 23rd to June 20th) using the full final dataset (2002-2009).

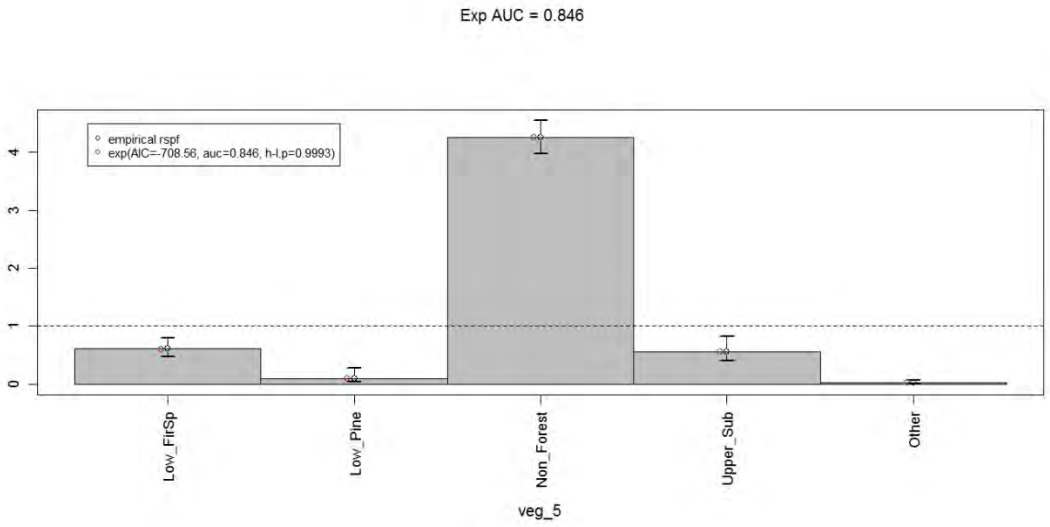


Figure 81. Tonquin caribou 71 selection for covariate Veg_5 during the calving season (May 23rd to June 20th) using the full final dataset (2002-2009).

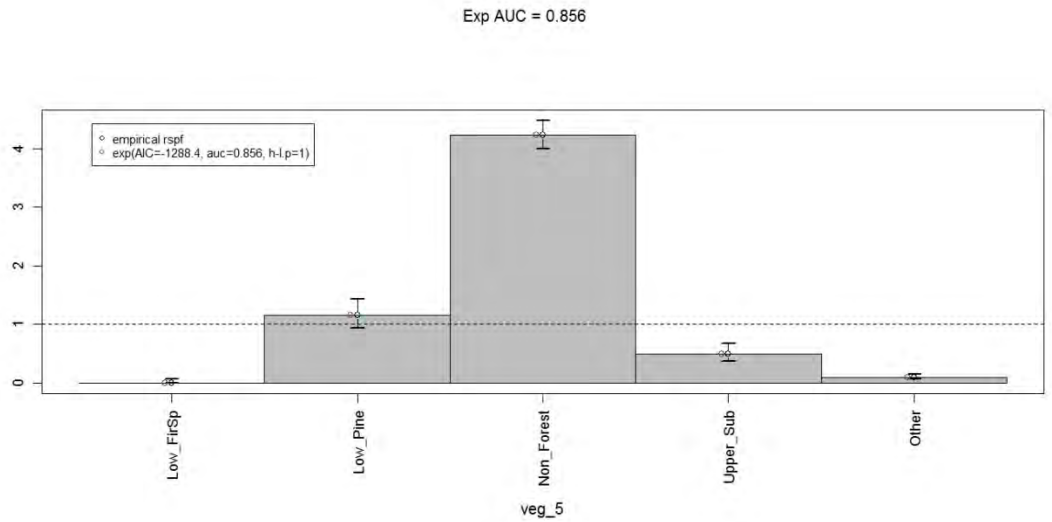
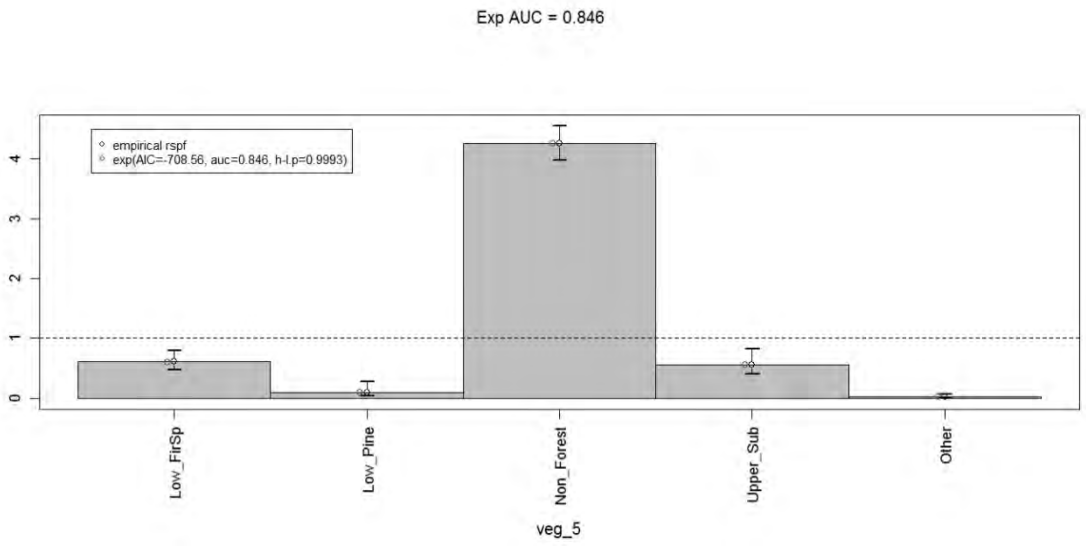


Figure 82. Tonquin caribou 101 selection for covariate Veg_5 during the calving season (May 23rd to June 20th) using the full final dataset (2002-2009).



Post Calving

Figure 83. Tonquin caribou 13 selection for covariate Veg_5 during the post-calving season (June 21st to July 19th) using the full final dataset (2002-2009).

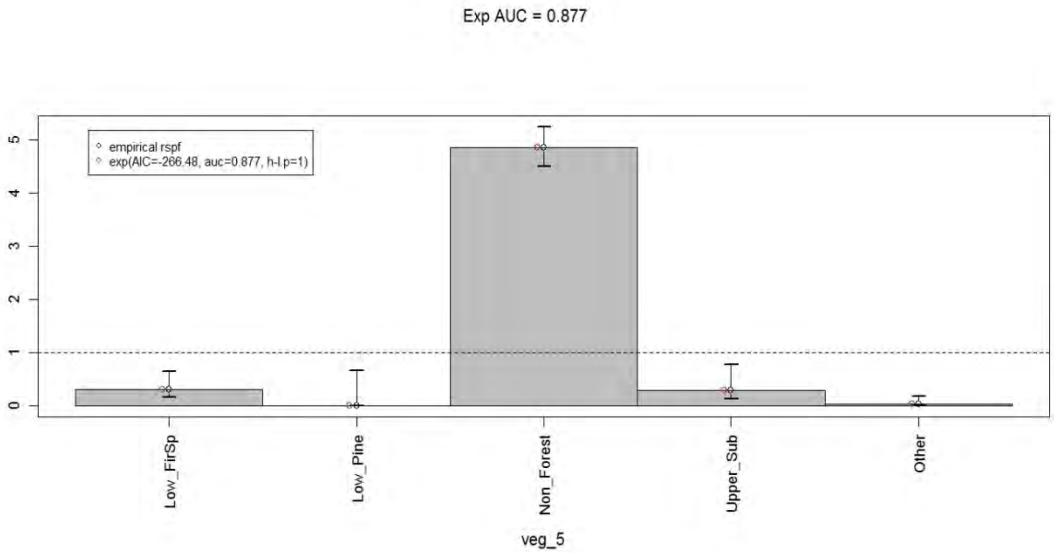


Figure 84. Tonquin caribou 21 selection for covariate Veg_5 during the post-calving season (June 21st to July 19th) using the full final dataset (2002-2009).

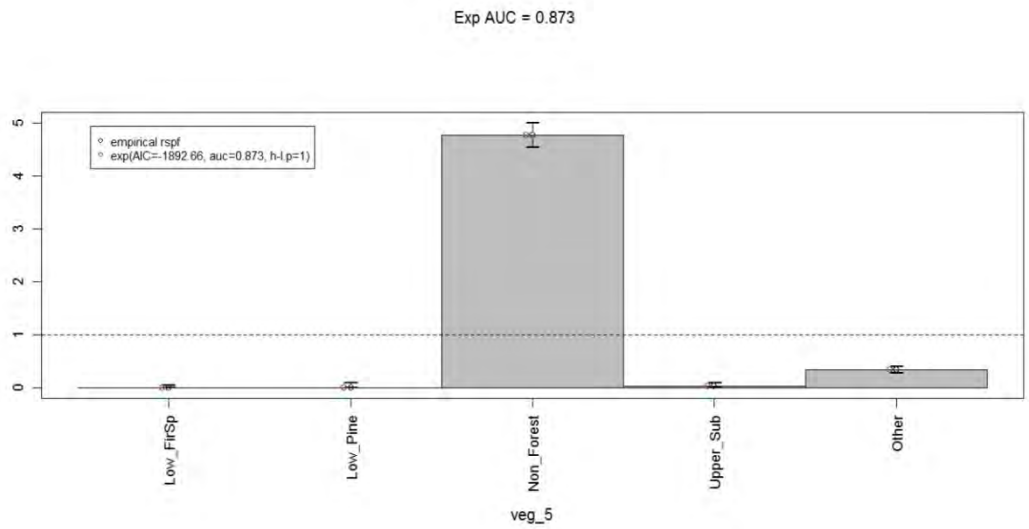


Figure 85. Tonquin caribou 34 selection for covariate Veg_5 during the post-calving season (June 21st to July 19th) using the full final dataset (2002-2009).

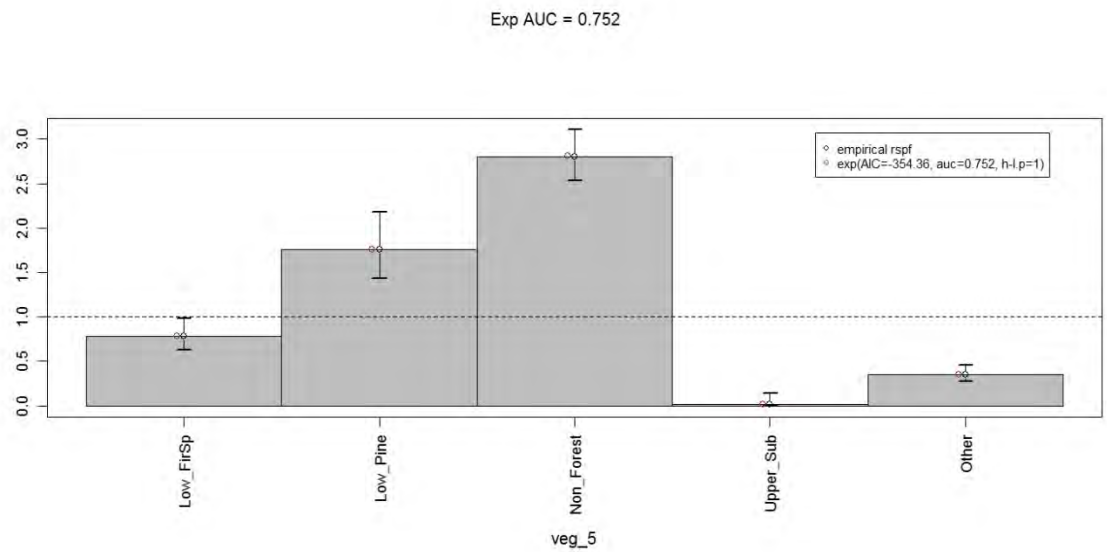


Figure 86. Tonquin caribou 41 selection for covariate Veg_5 during the post-calving season (June 21st to July 19th) using the full final dataset (2002-2009).

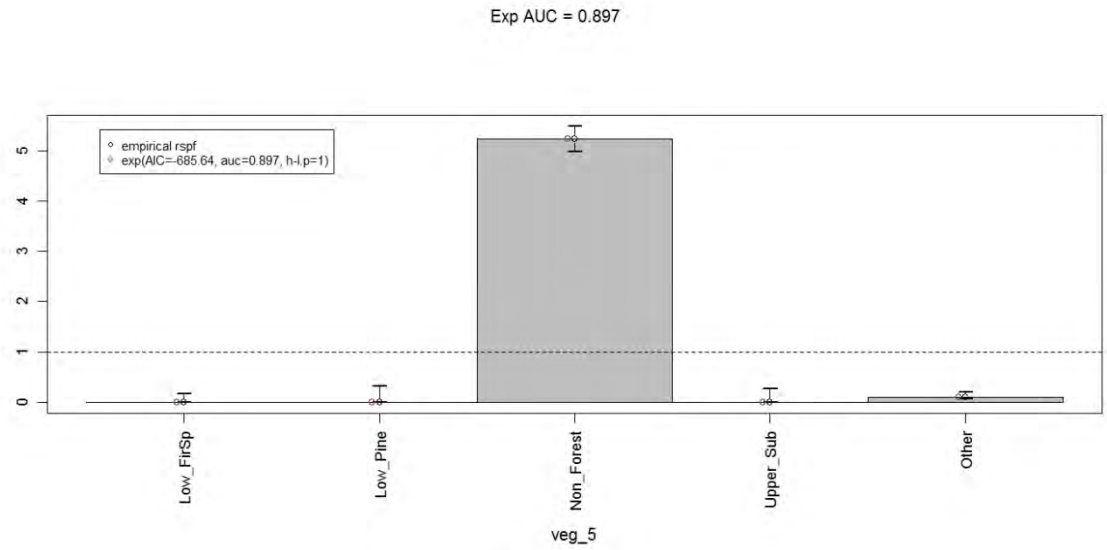


Figure 87. Tonquin caribou 64 selection for covariate Veg_5 during the post-calving season (June 21st to July 19th) using the full final dataset (2002-2009).

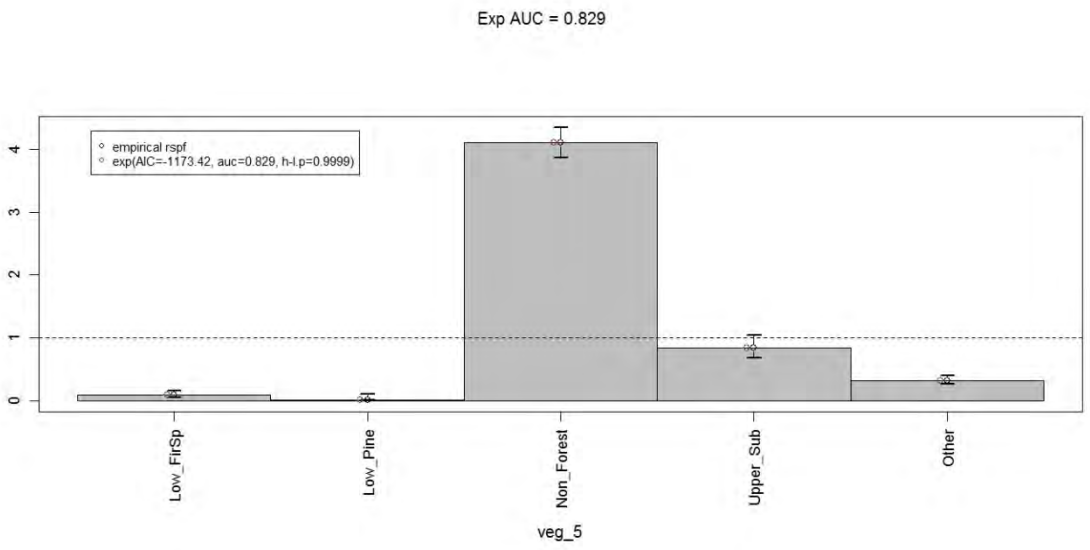


Figure 88. Tonquin caribou 69 selection for covariate Veg_5 during the post-calving season (June 21st to July 19th) using the full final dataset (2002-2009).

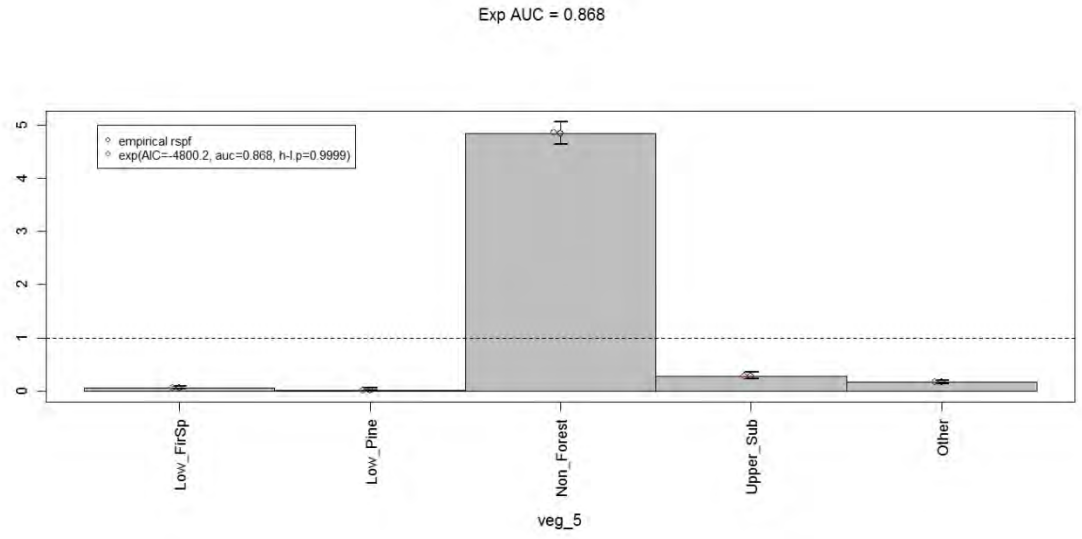
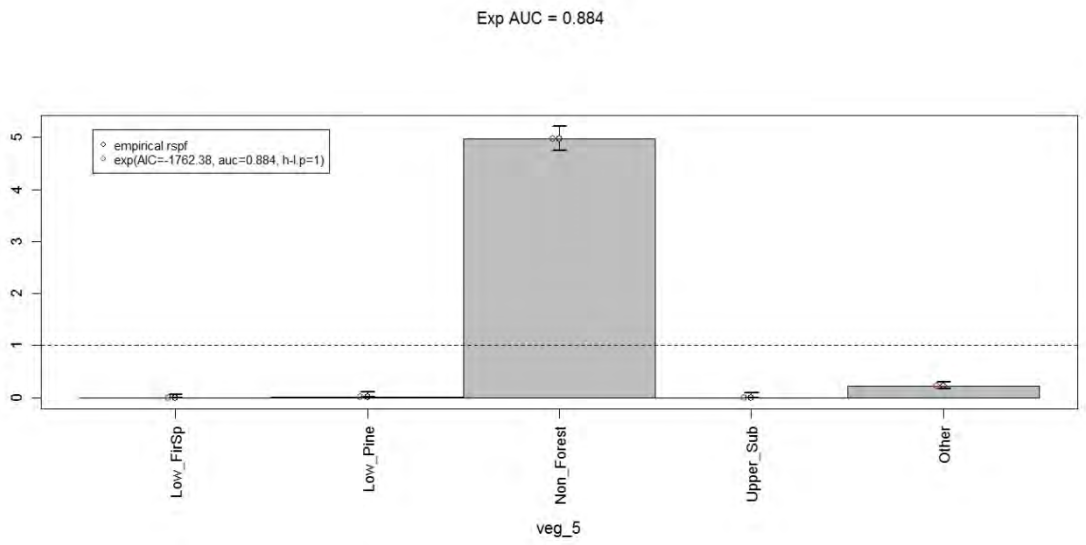


Figure 89. Tonquin caribou 71 selection for covariate Veg_5 during the post-calving season (June 21st to July 19th) using the full final dataset (2002-2009).



Summer

Figure 90. Tonquin caribou 12 selection for covariate Veg_5 during the summer season (July 20th to September 26th) using the full final dataset (2002-2009).

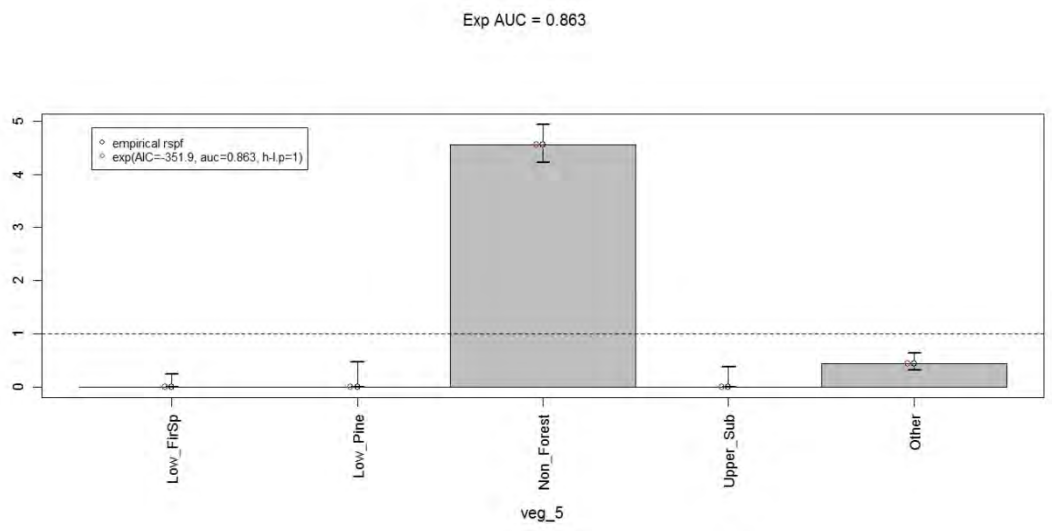


Figure 91. Tonquin caribou 13 selection for covariate Veg_5 during the summer season (July 20th to September 26th) using the full final dataset (2002-2009).

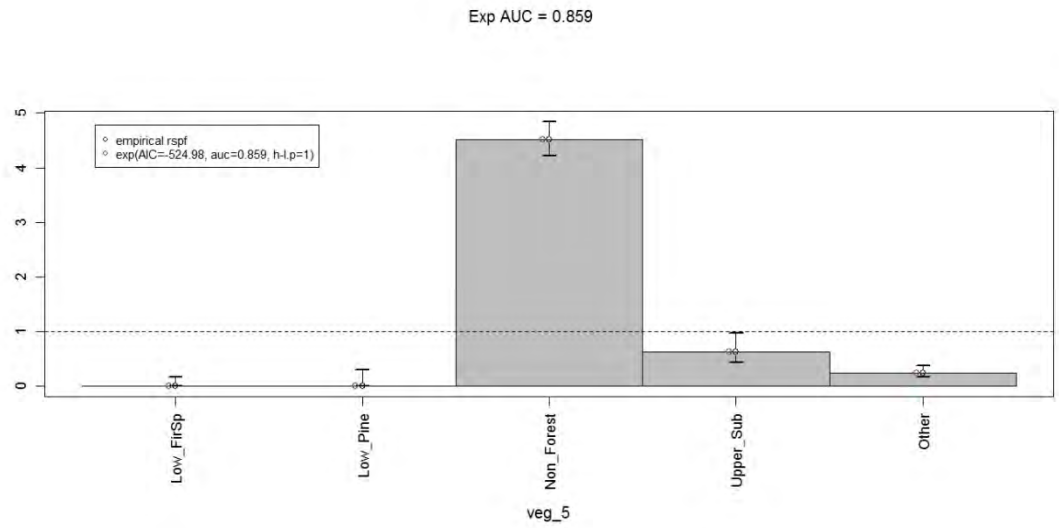


Figure 92. Tonquin caribou 14 selection for covariate Veg_5 during the summer season (July 20th to September 26th) using the full final dataset (2002-2009).

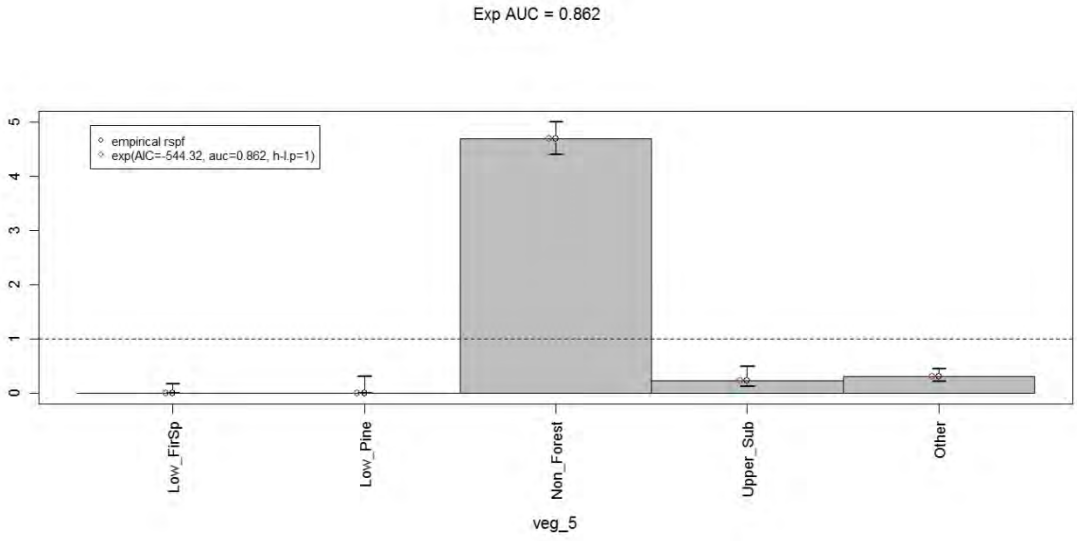


Figure 93. Tonquin caribou 21 selection for covariate Veg_5 during the summer season (July 20th to September 26th) using the full final dataset (2002-2009).

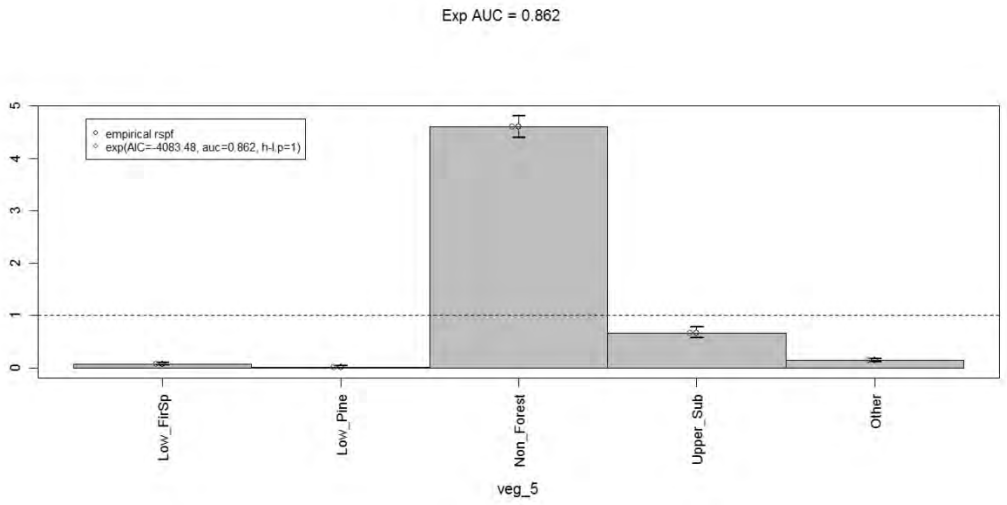


Figure 94. Tonquin caribou 34 selection for covariate Veg_5 during the summer season (July 20th to September 26th) using the full final dataset (2002-2009).

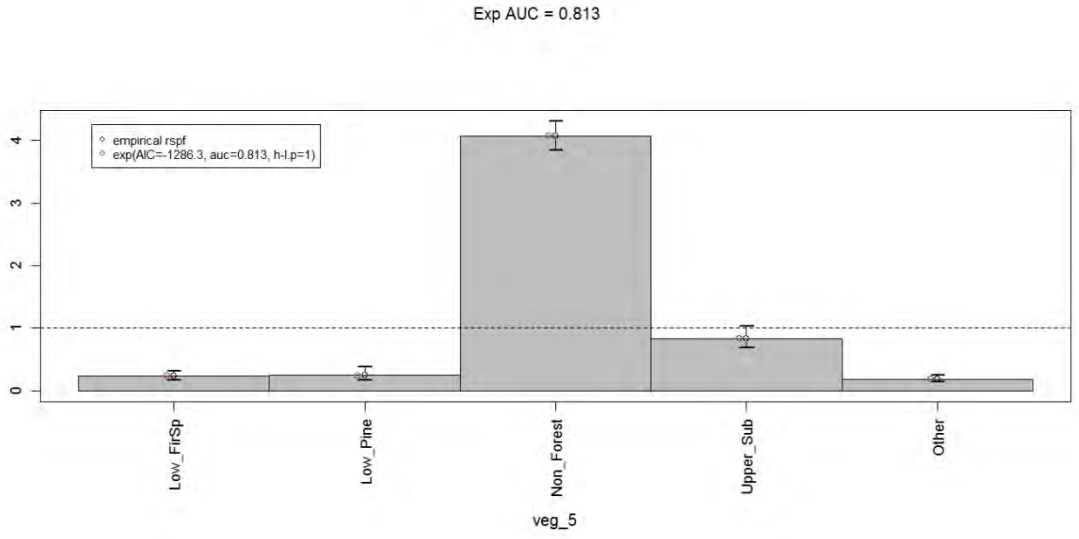


Figure 95. Tonquin caribou 41 selection for covariate Veg_5 during the summer season (July 20th to September 26th) using the full final dataset (2002-2009).

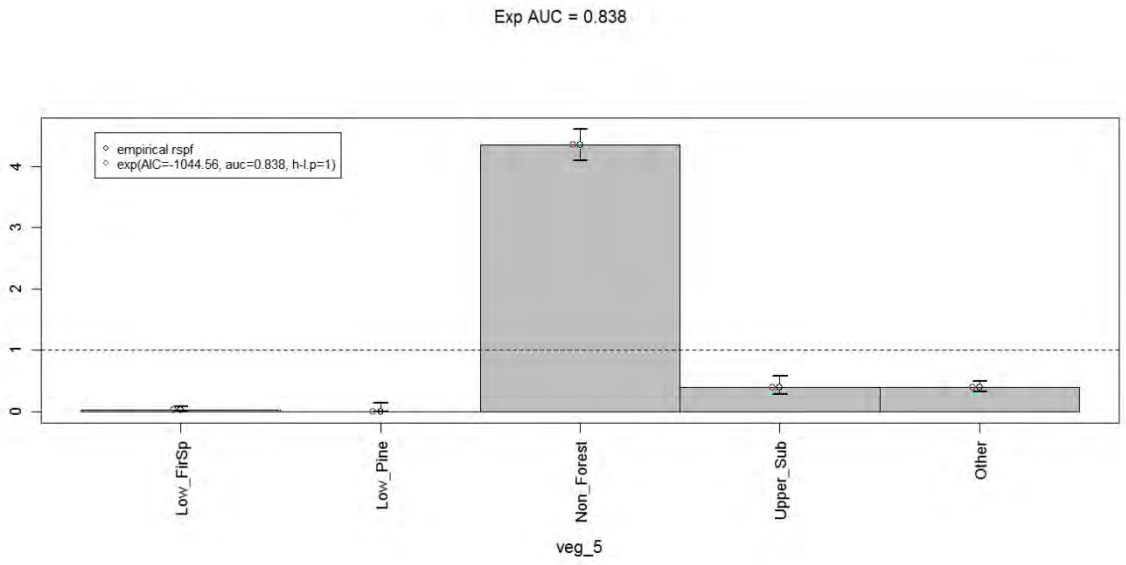


Figure 96. Tonquin caribou 64 selection for covariate Veg_5 during the summer season (July 20th to September 26th) using the full final dataset (2002-2009).

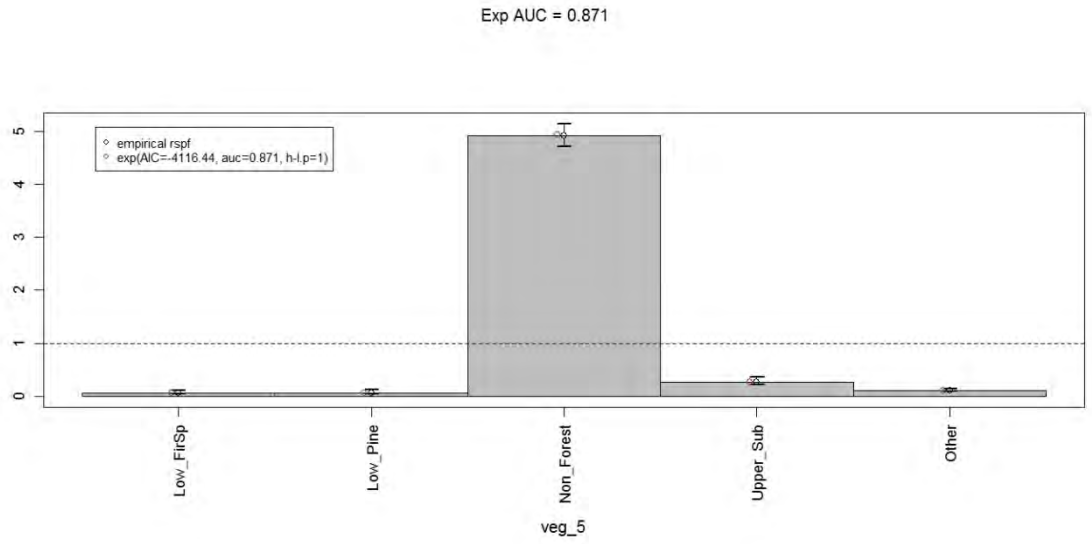


Figure 97. Tonquin caribou 69 selection for covariate Veg_5 during the summer season (July 20th to September 26th) using the full final dataset (2002-2009).

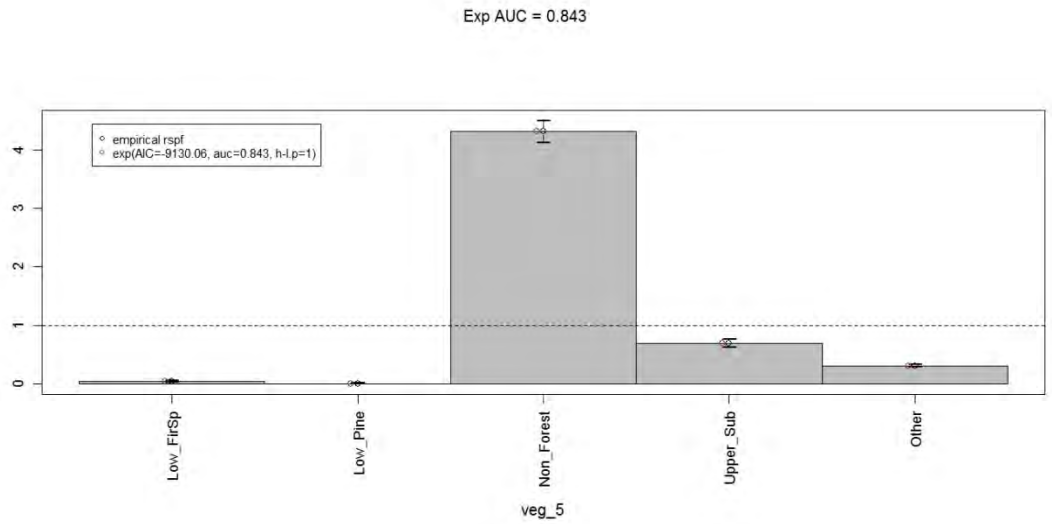
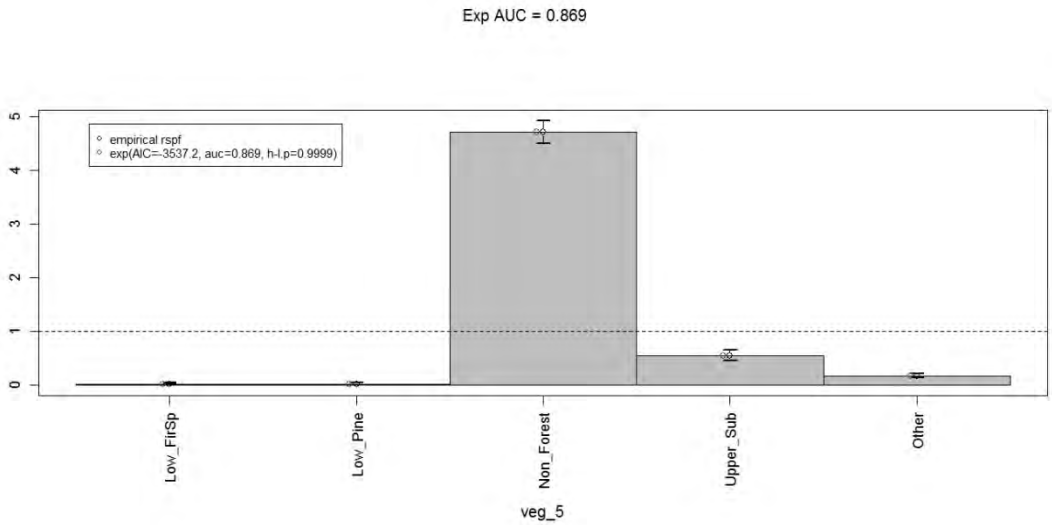


Figure 98. Tonquin caribou 71 selection for covariate Veg_5 during the summer season (July 20th to September 26th) using the full final dataset (2002-2009).



Rut

Figure 99. Tonquin caribou 12 selection for covariate Veg_5 during the rutting season (September 27th to October 31st) using the full final dataset (2002-2009).

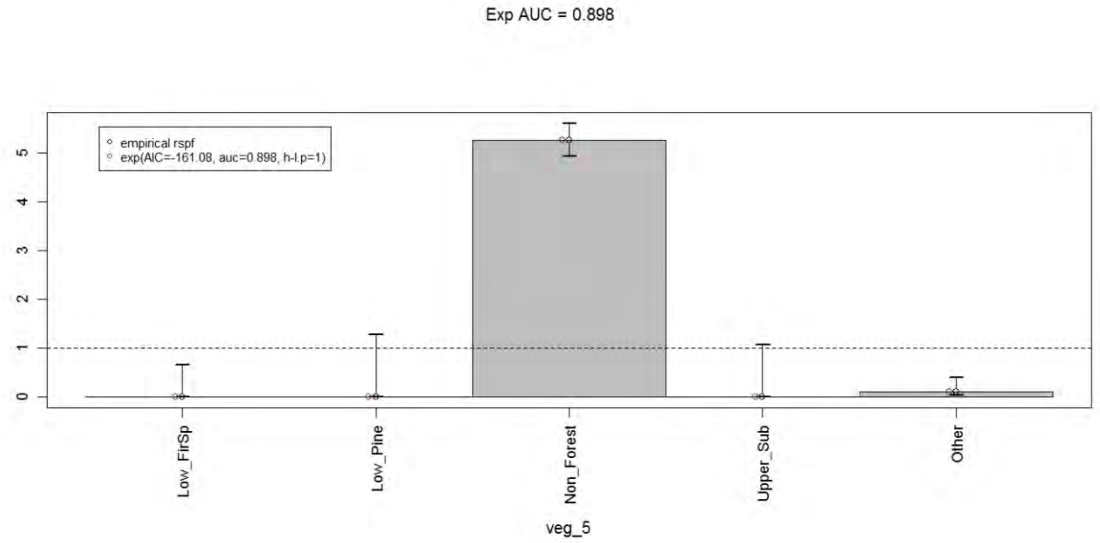


Figure 100. Tonquin caribou 13 selection for covariate Veg_5 during the rutting season (September 27th to October 31st) using the full final dataset (2002-2009).

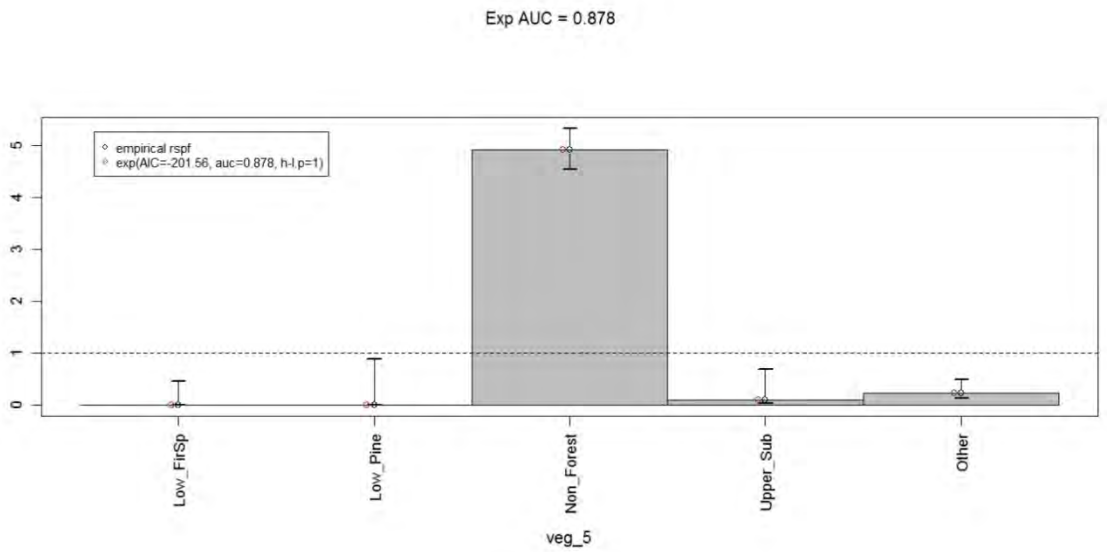


Figure 101. Tonquin caribou 14 selection for covariate Veg_5 during the rutting season (September 27th to October 31st) using the full final dataset (2002-2009).

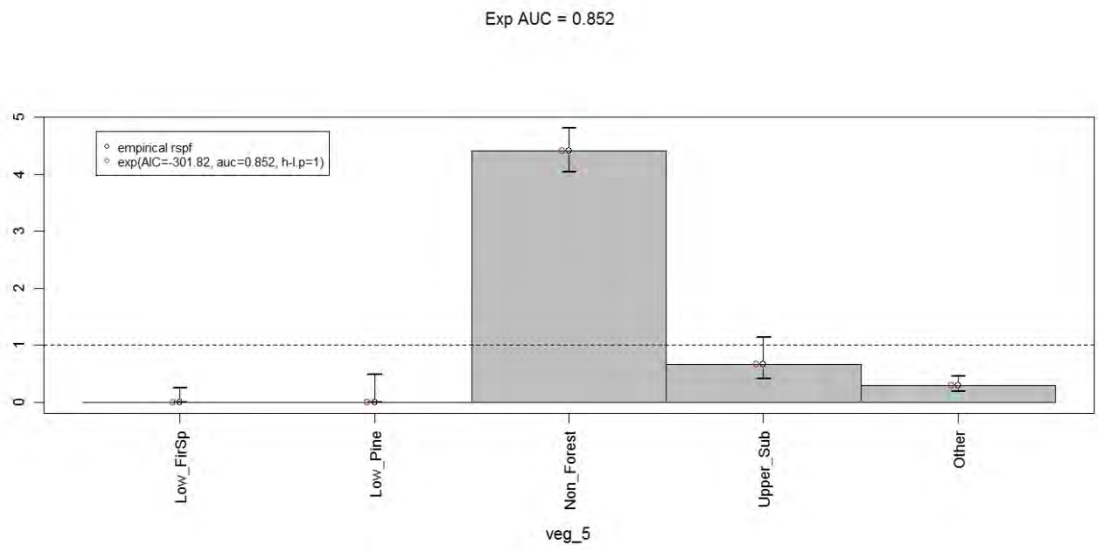


Figure 102. Tonquin caribou 21 selection for covariate Veg_5 during the rutting season (September 27th to October 31st) using the full final dataset (2002-2009).

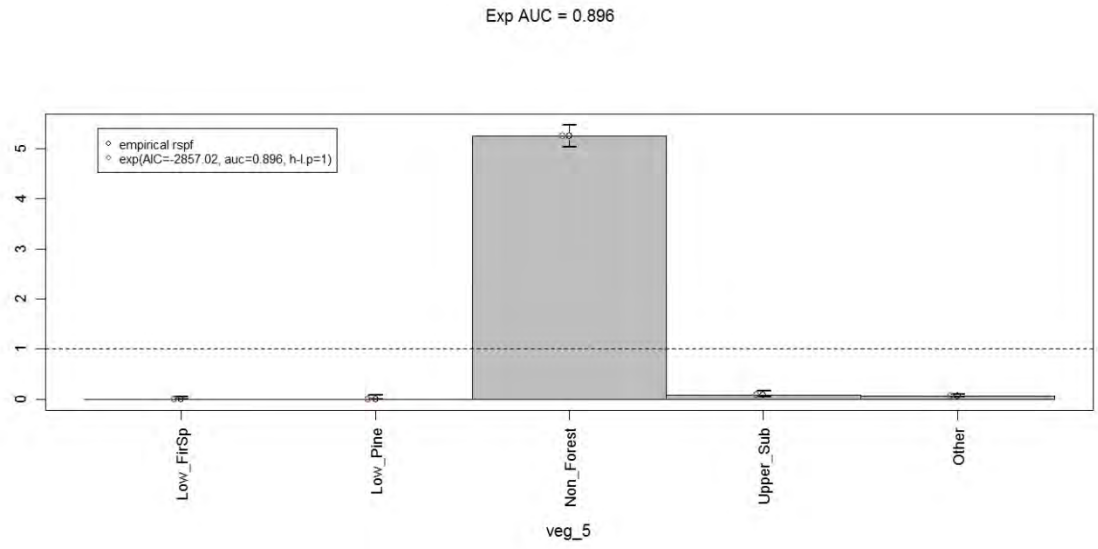


Figure 103. Tonquin caribou 34 selection for covariate Veg_5 during the rutting season (September 27th to October 31st) using the full final dataset (2002-2009).

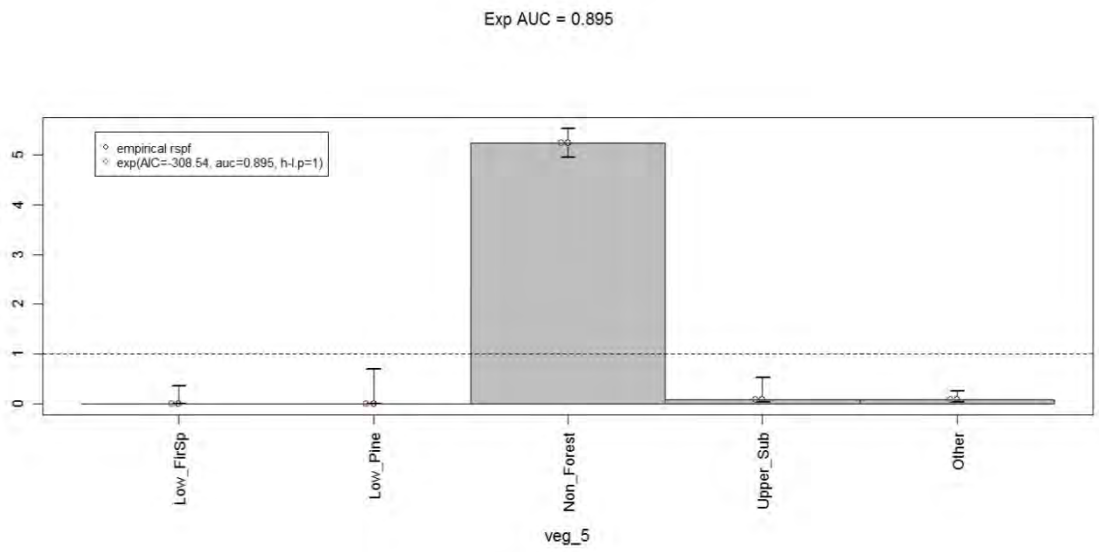


Figure 104. Tonquin caribou 41 selection for covariate Veg_5 during the rutting season (September 27th to October 31st) using the full final dataset (2002-2009).

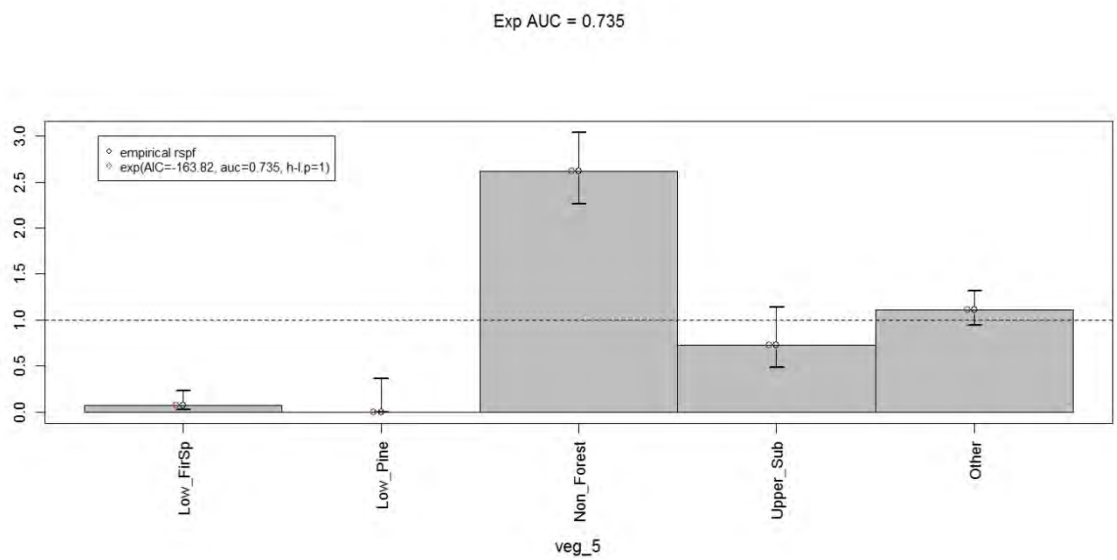


Figure 105. Tonquin caribou 64 selection for covariate Veg_5 during the rutting season (September 27th to October 31st) using the full final dataset (2002-2009).

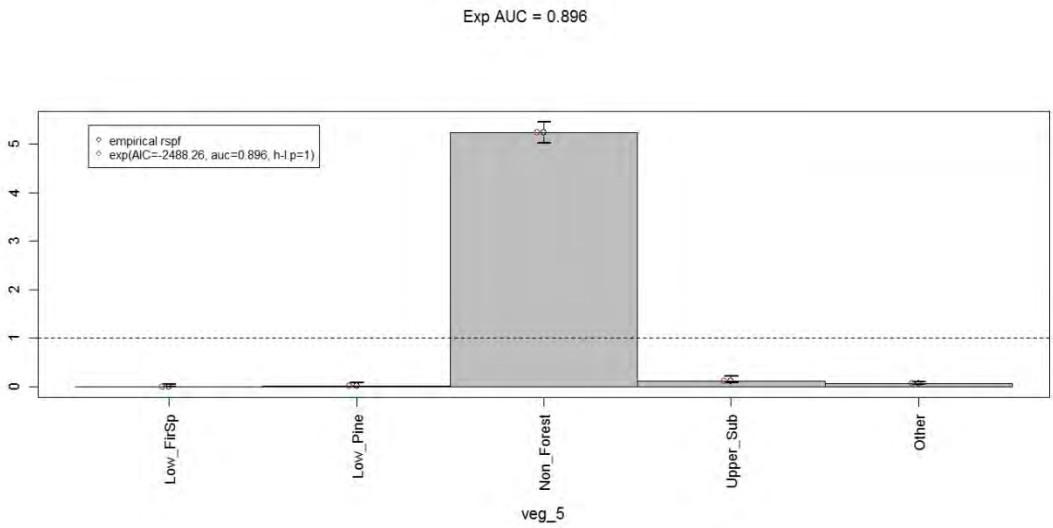


Figure 106. Tonquin caribou 69 selection for covariate Veg_5 during the rutting season (September 27th to October 31st) using the full final dataset (2002-2009).

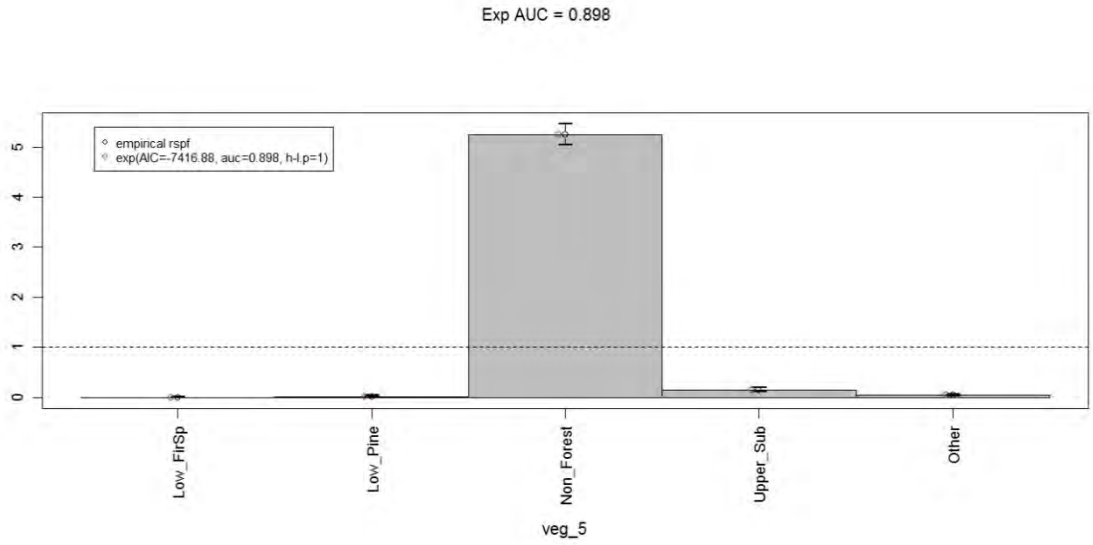
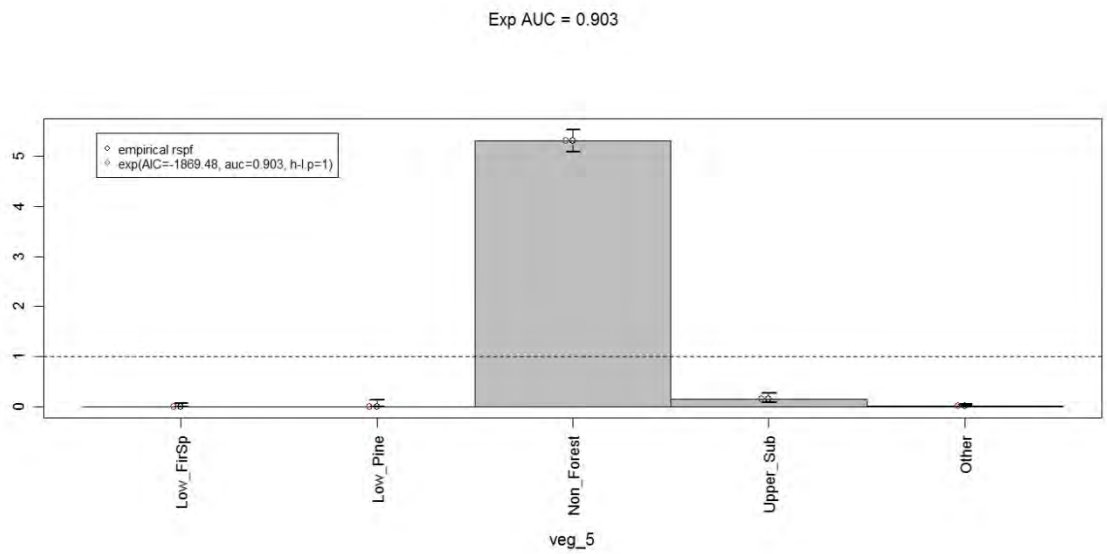


Figure 107. Tonquin caribou 71 selection for covariate Veg_5 during the rutting season (September 27th to October 31st) using the full final dataset (2002-2009).



Early Winter

Figure 108. Tonquin caribou 12 selection for covariate Veg_5 during the early winter season (November 1st to January 21st) using the full final dataset (2002-2009).

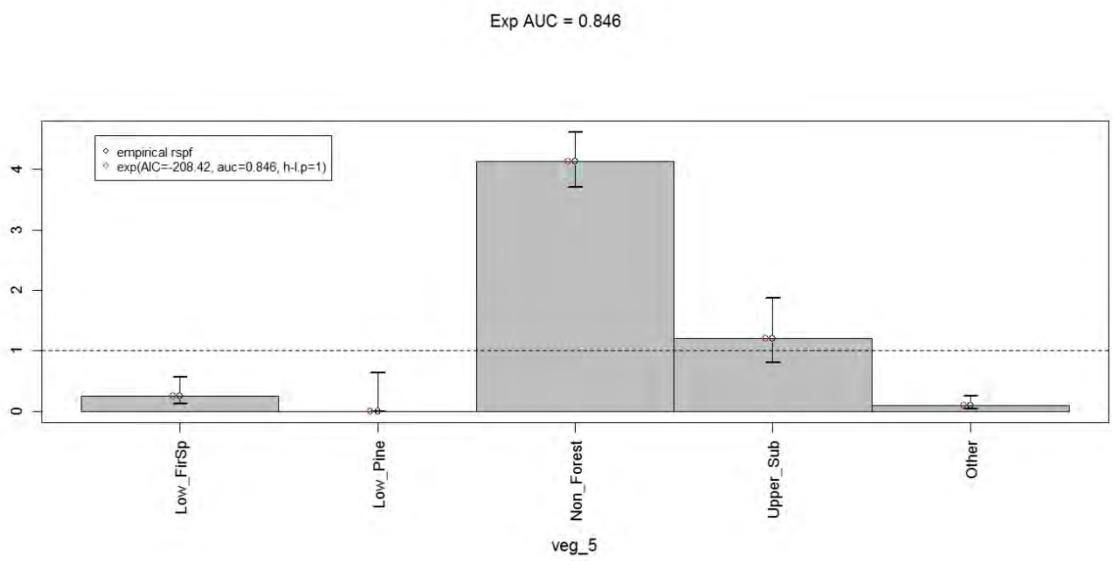


Figure 109. Tonquin caribou 13 selection for covariate Veg_5 during the early winter season (November 1st to January 21st) using the full final dataset (2002-2009).

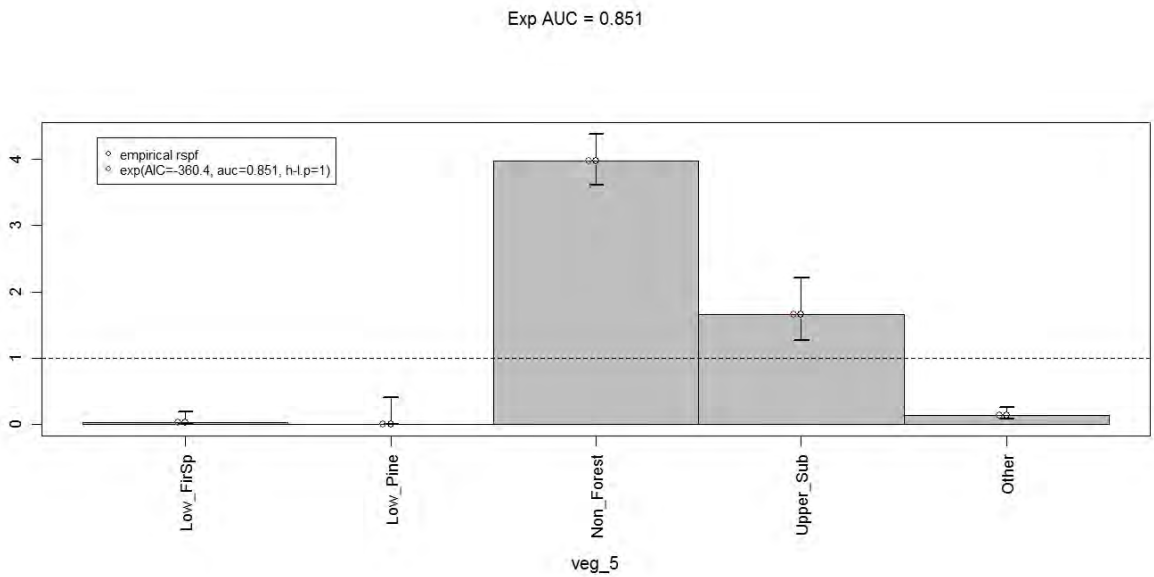


Figure 110. Tonquin caribou 14 selection for covariate Veg_5 during the early winter season (November 1st to January 21st) using the full final dataset (2002-2009).

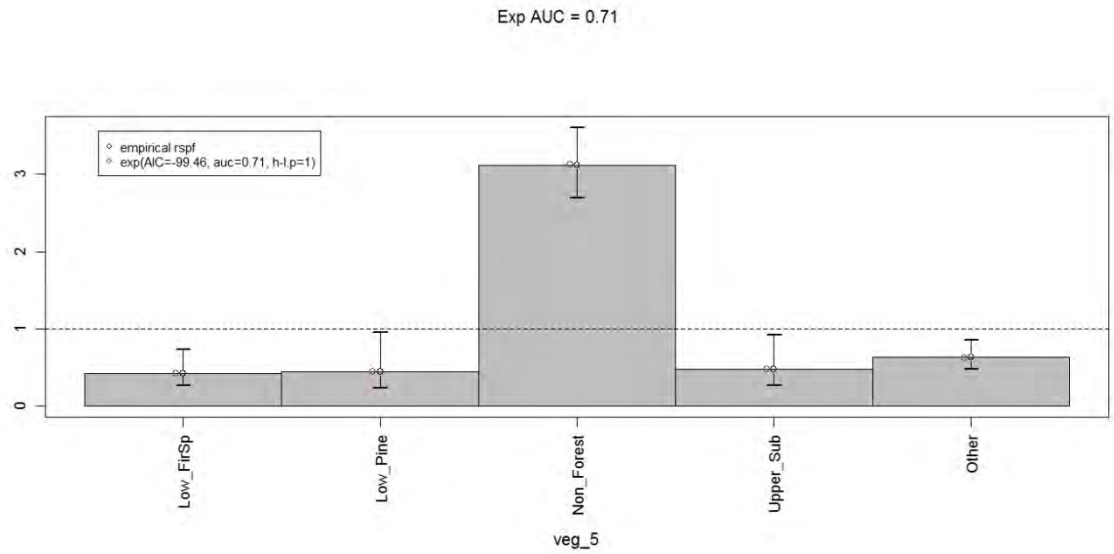


Figure 111. Tonquin caribou 21 selection for covariate Veg_5 during the early winter season (November 1st to January 21st) using the full final dataset (2002-2009).

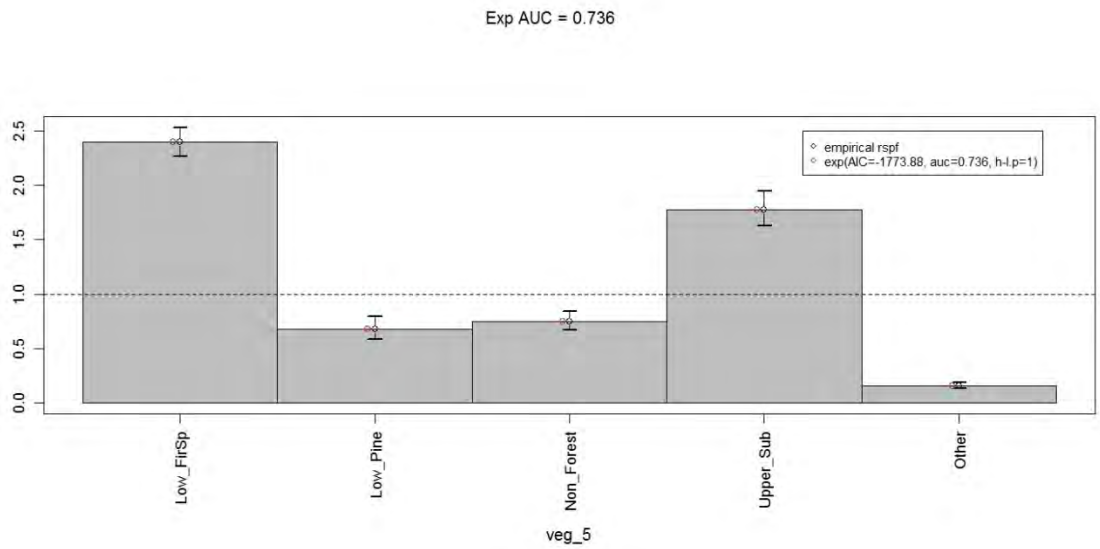


Figure 112. Tonquin caribou 34 selection for covariate Veg_5 during the early winter season (November 1st to January 21st) using the full final dataset (2002-2009).

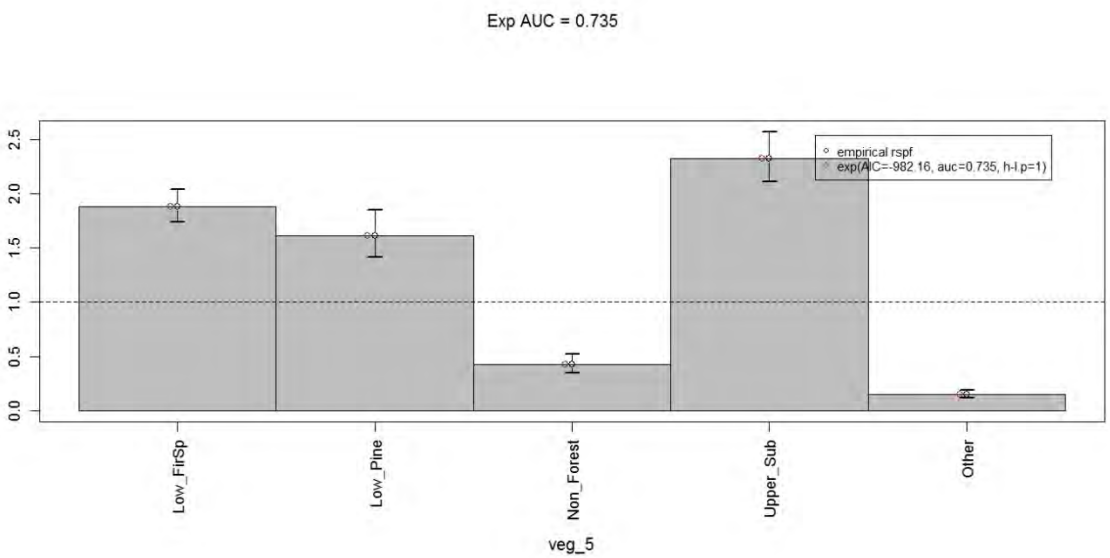


Figure 113. Tonquin caribou 36 selection for covariate Veg_5 during the early winter season (November 1st to January 21st) using the full final dataset (2002-2009).

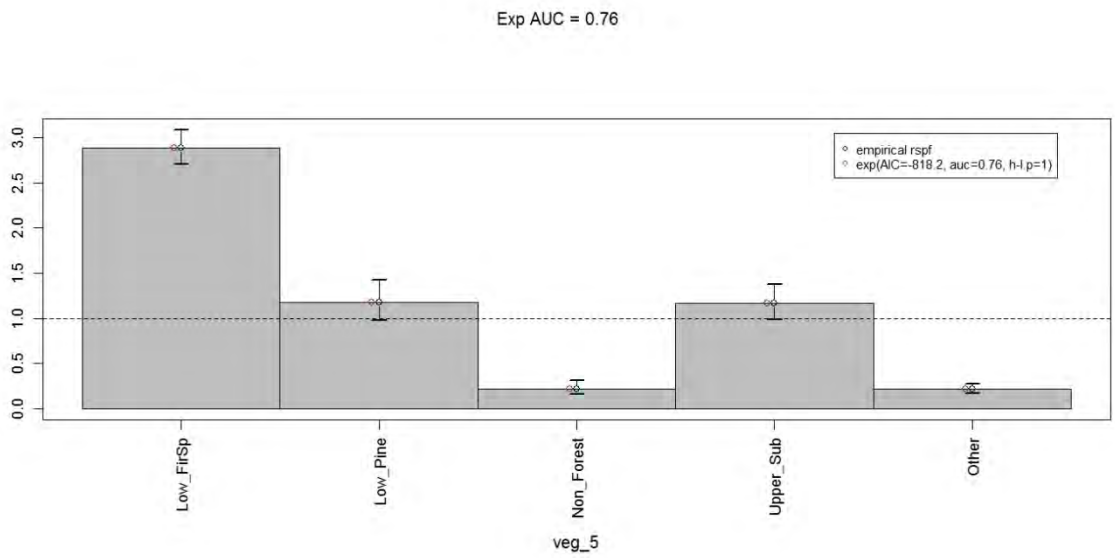


Figure 114. Tonquin caribou 43 selection for covariate Veg_5 during the early winter season (November 1st to January 21st) using the full final dataset (2002-2009).

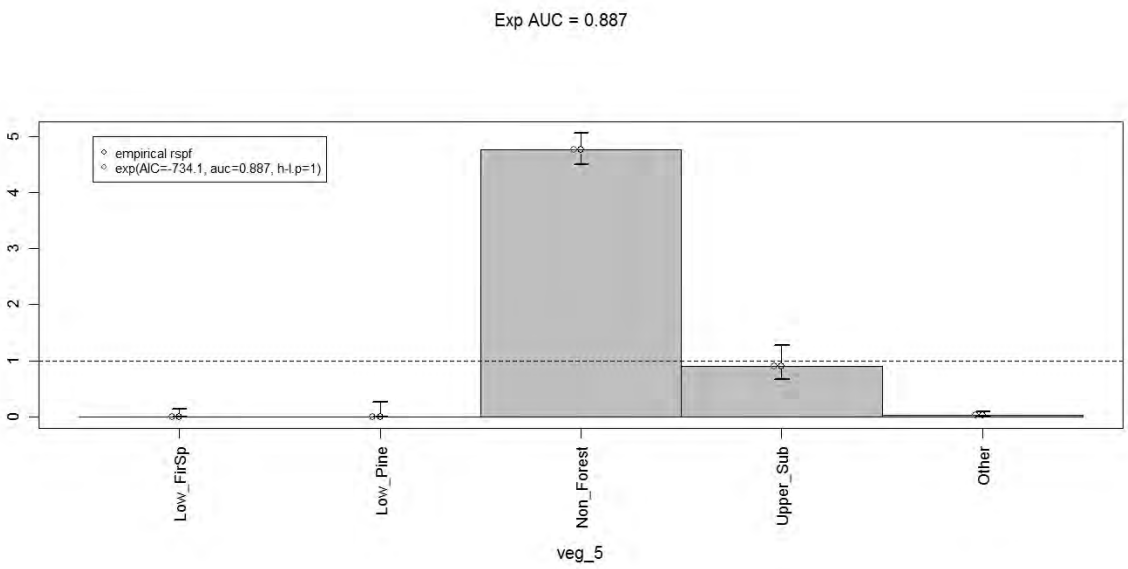


Figure 115. Tonquin caribou 59 selection for covariate Veg_5 during the early winter season (November 1st to January 21st) using the full final dataset (2002-2009).

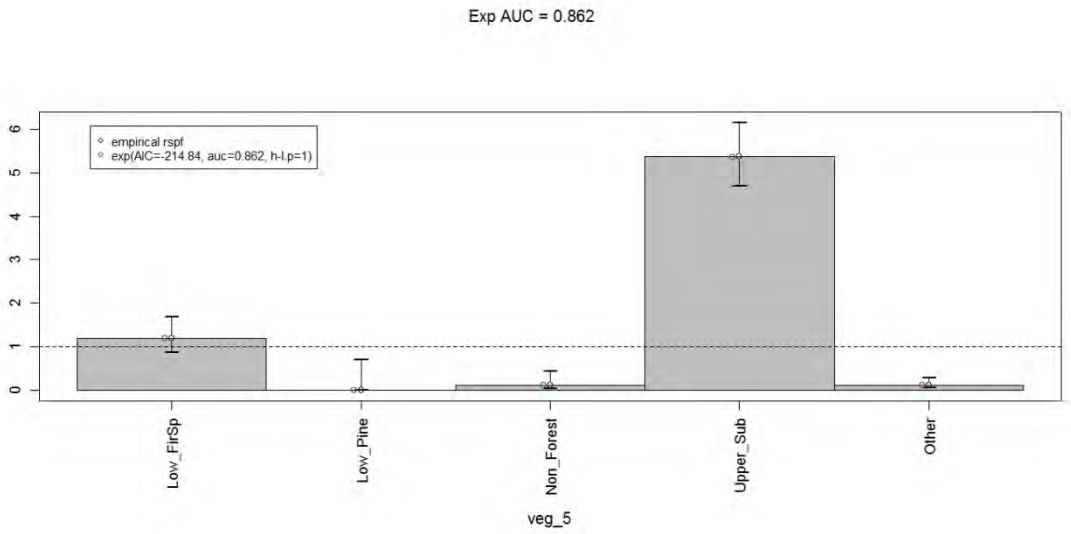


Figure 116. Tonquin caribou 64 selection for covariate Veg_5 during the early winter season (November 1st to January 21st) using the full final dataset (2002-2009).

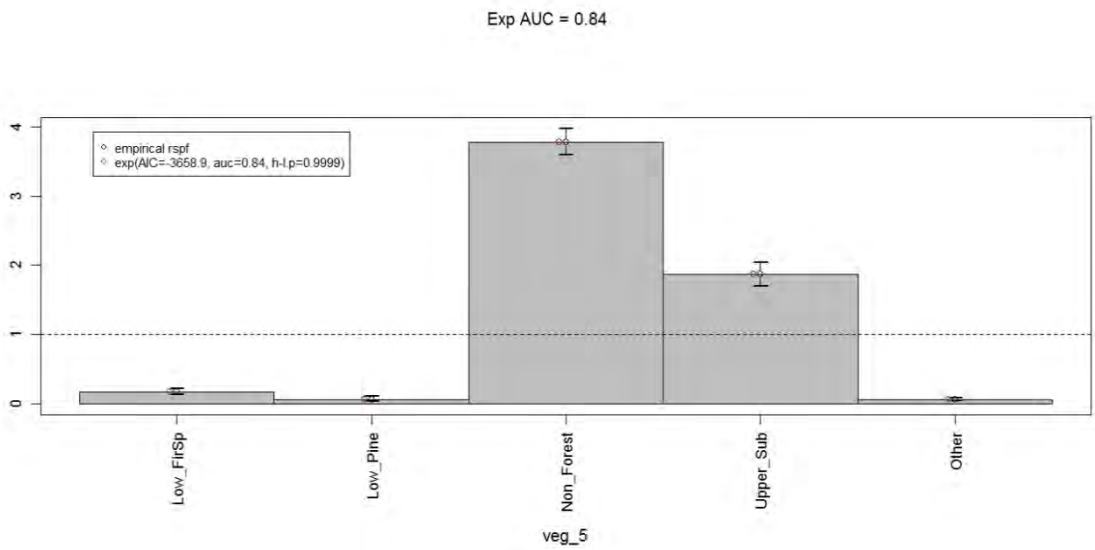


Figure 117. Tonquin caribou 65 selection for covariate Veg_5 during the early winter season (November 1st to January 21st) using the full final dataset (2002-2009).

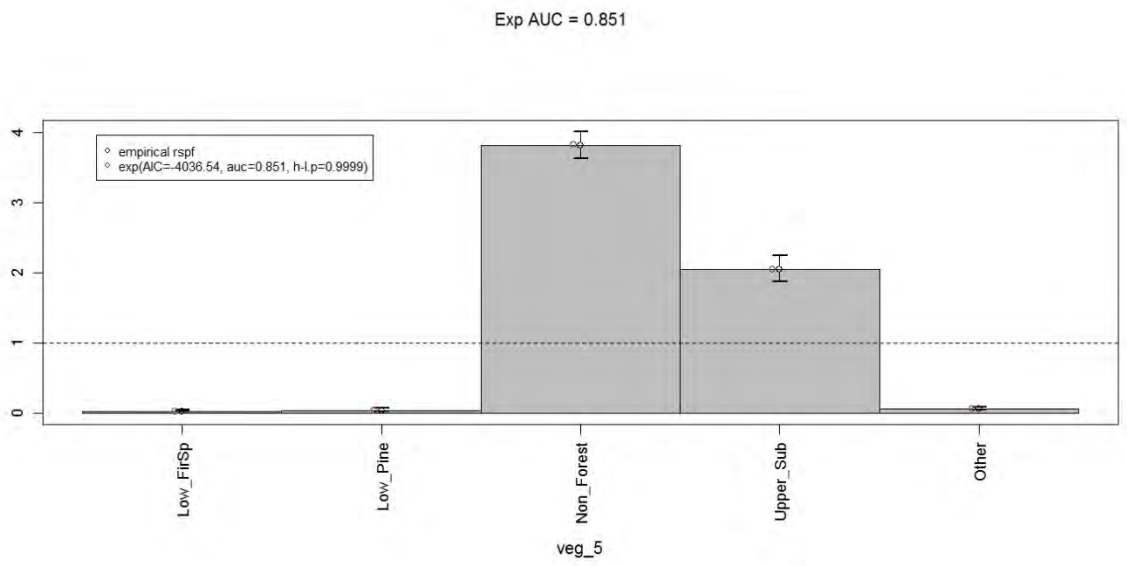


Figure 118. Tonquin caribou 69 selection for covariate Veg_5 during the early winter season (November 1st to January 21st) using the full final dataset (2002-2009).

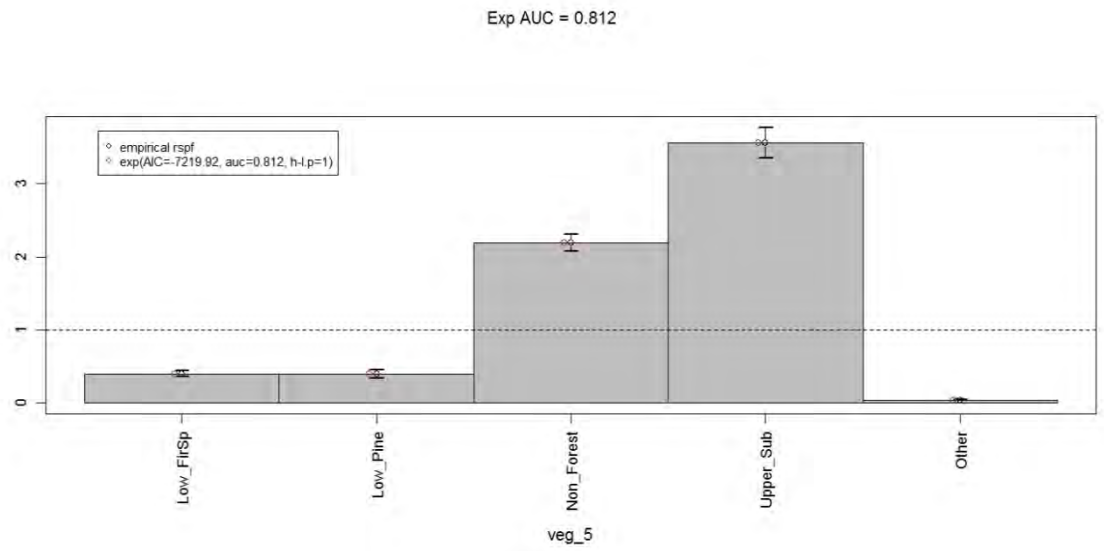


Figure 119. Tonquin caribou 71 selection for covariate Veg_5 during the early winter season (November 1st to January 21st) using the full final dataset (2002-2009).

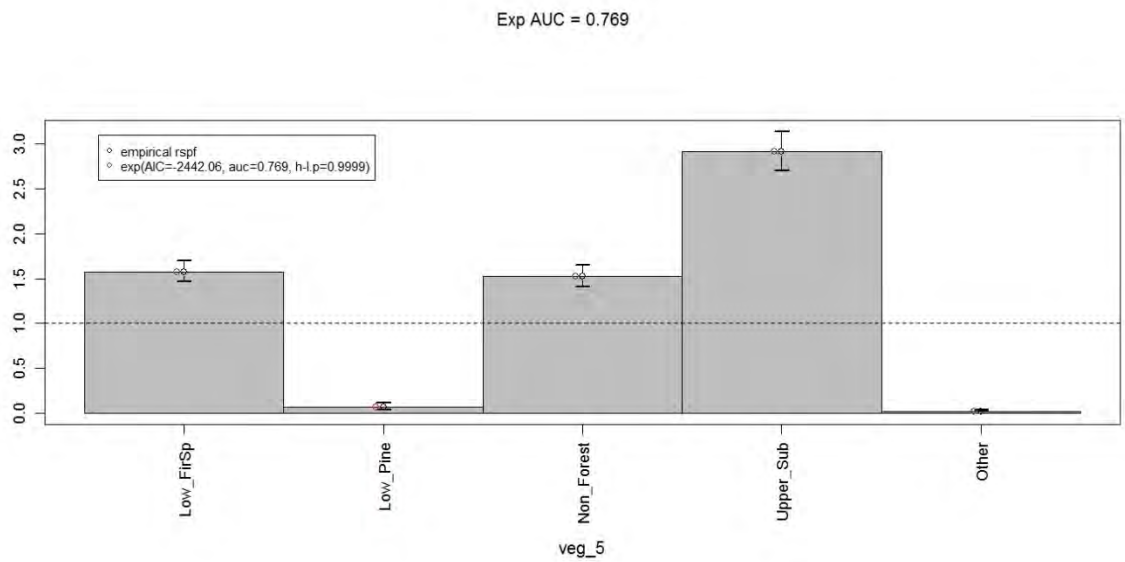
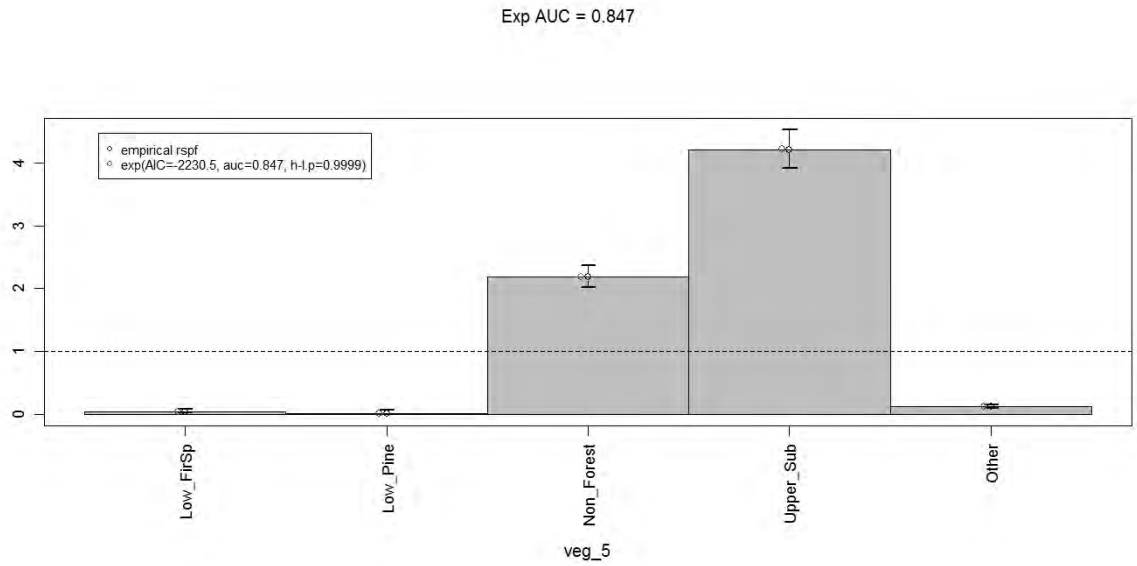


Figure 120. Tonquin caribou 101 selection for covariate Veg_5 during the early winter season (November 1st to January 21st) using the full final dataset (2002-2009).



Late Winter

Figure 121. Tonquin caribou 13 selection for covariate Veg_5 during the late winter (January 22nd to May 22nd) season using the full final dataset (2002-2009).

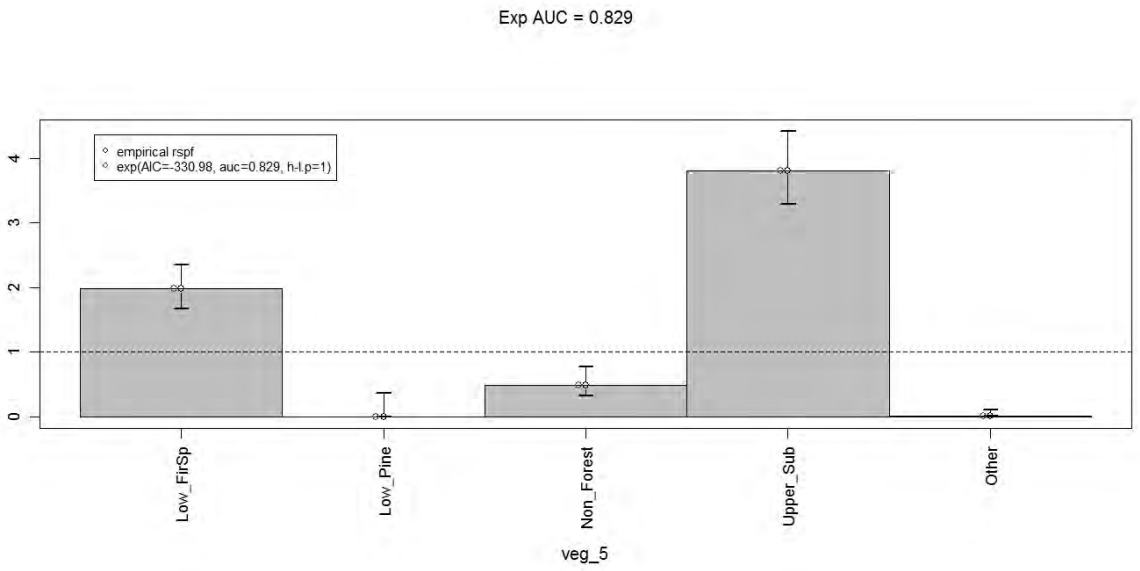


Figure 122. Tonquin caribou 21 selection for covariate Veg_5 during the late winter (January 22nd to May 22nd) season using the full final dataset (2002-2009).

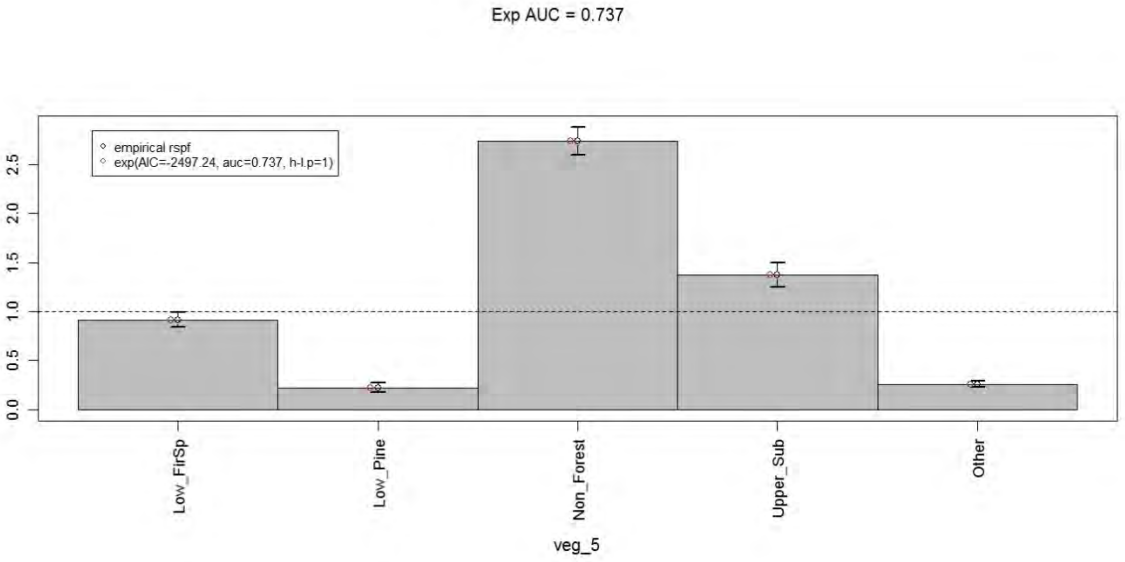


Figure 123. Tonquin caribou 34 selection for covariate Veg_5 during the late winter (January 22nd to May 22nd) season using the full final dataset (2002-2009).

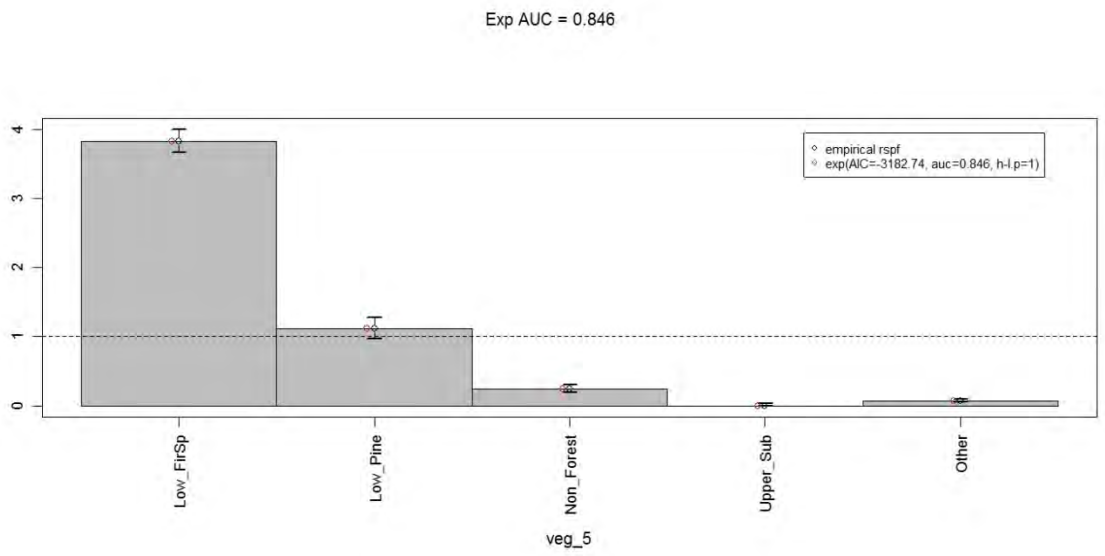


Figure 124. Tonquin caribou 36 selection for covariate Veg_5 during the late winter (January 22nd to May 22nd) season using the full final dataset (2002-2009).

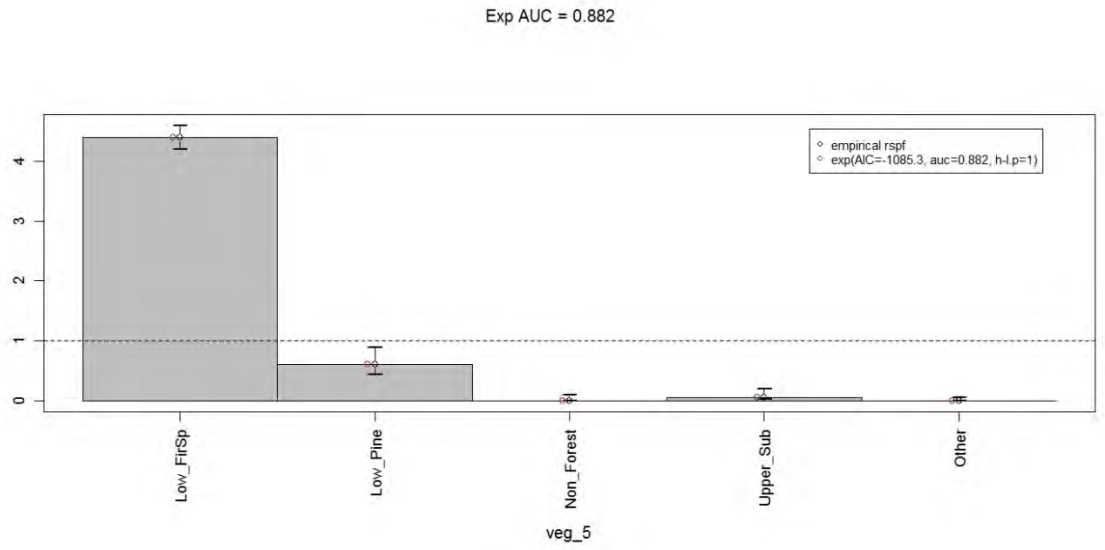


Figure 125. Tonquin caribou 41 selection for covariate Veg_5 during the late winter (January 22nd to May 22nd) season using the full final dataset (2002-2009).

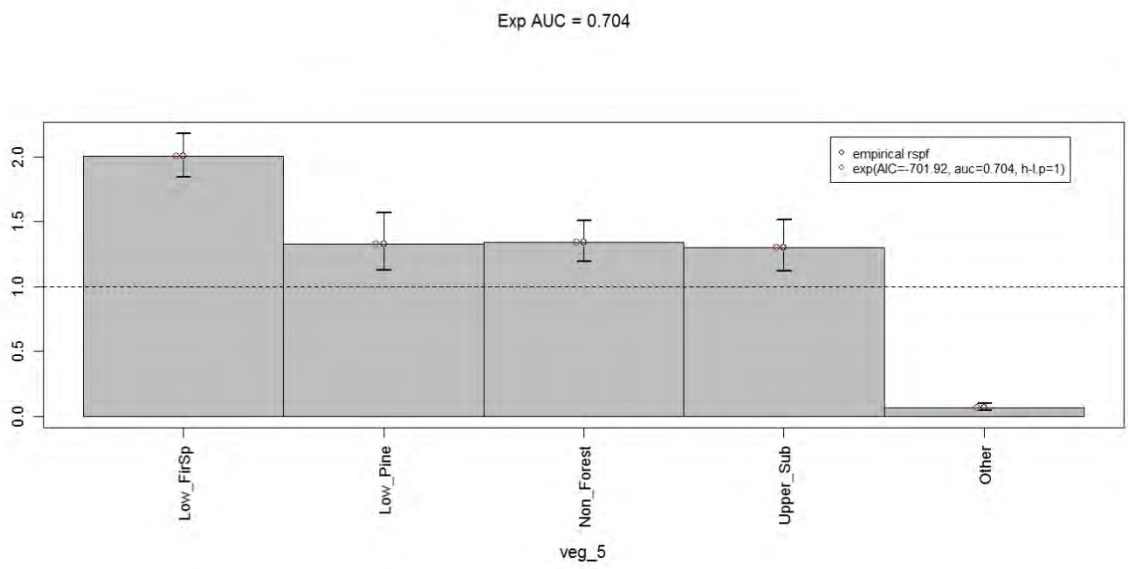


Figure 126. Tonquin caribou 43 selection for covariate Veg_5 during the late winter (January 22nd to May 22nd) season using the full final dataset (2002-2009).

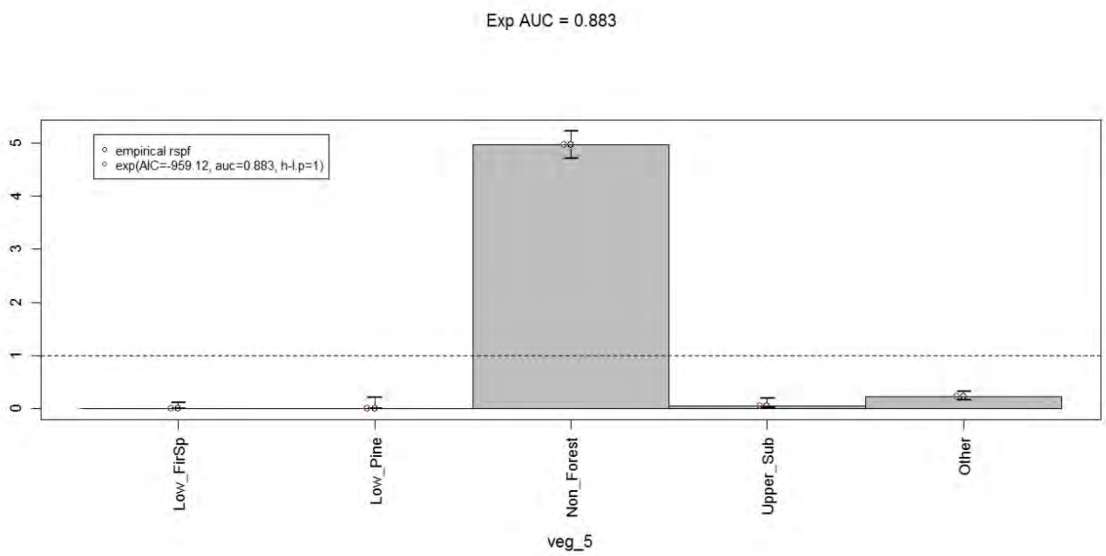


Figure 127. Tonquin caribou 59 selection for covariate Veg_5 during the late winter (January 22nd to May 22nd) season using the full final dataset (2002-2009).

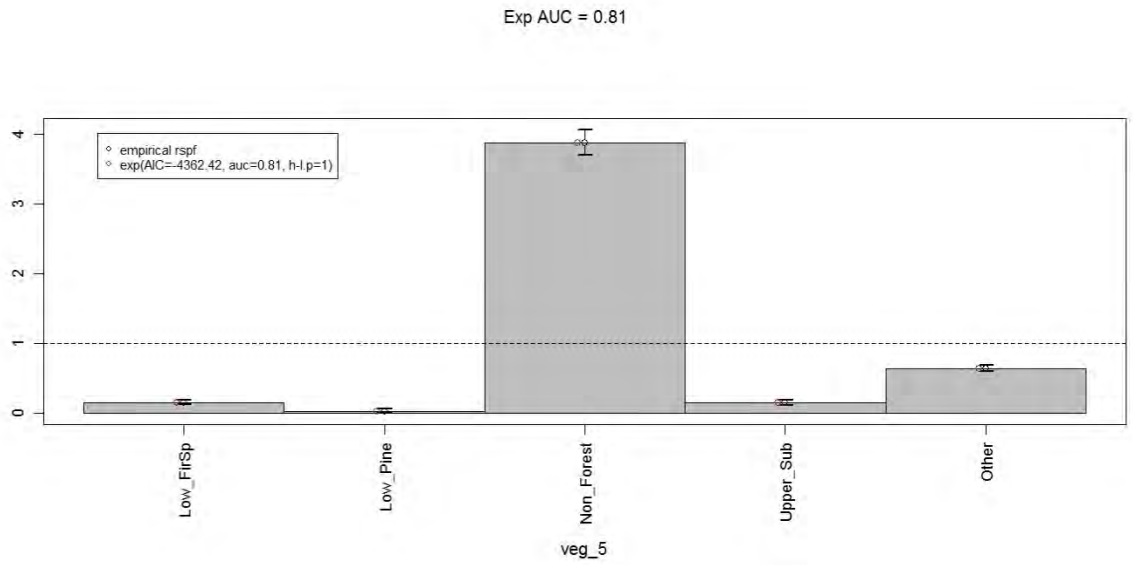


Figure 128. Tonquin caribou 64 selection for covariate Veg_5 during the late winter (January 22nd to May 22nd) season using the full final dataset (2002-2009).

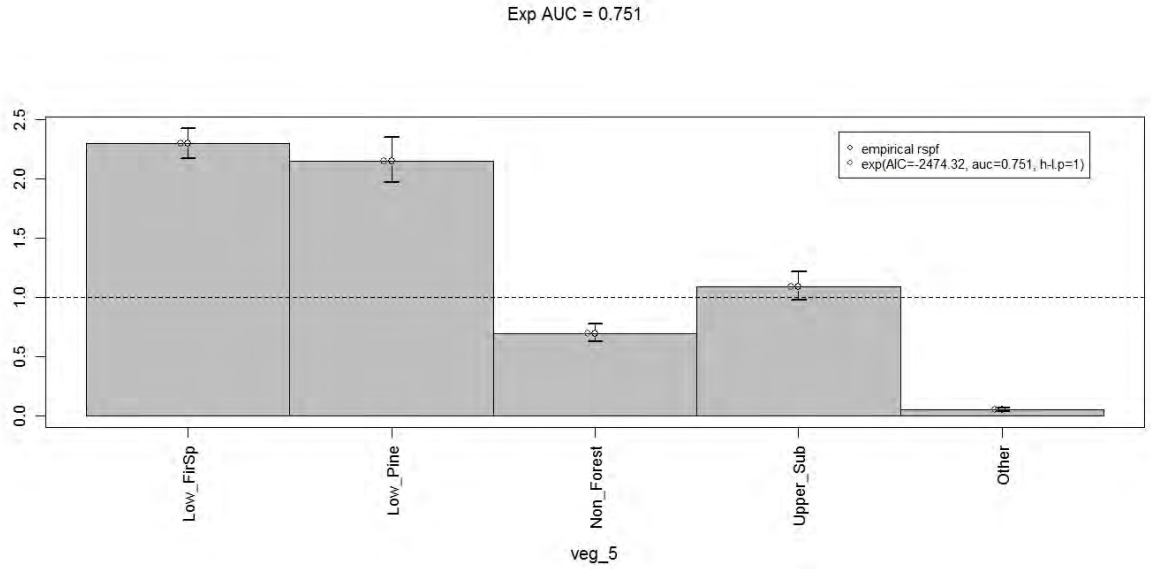


Figure 129. Tonquin caribou 65 selection for covariate Veg_5 during the late winter (January 22nd to May 22nd) season using the full final dataset (2002-2009).

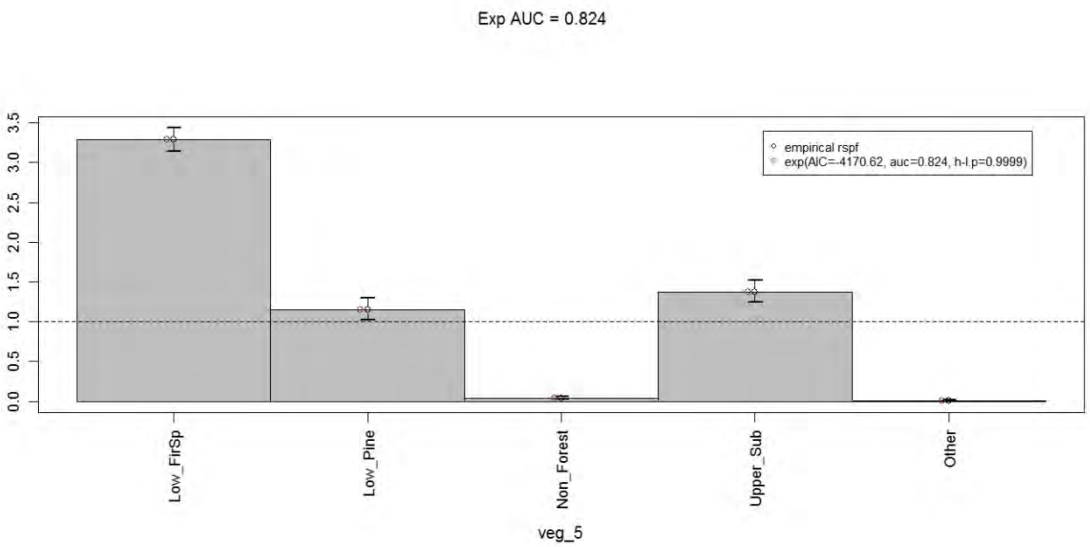


Figure 130. Tonquin caribou 69 selection for covariate Veg_5 during the late winter (January 22nd to May 22nd) season using the full final dataset (2002-2009).

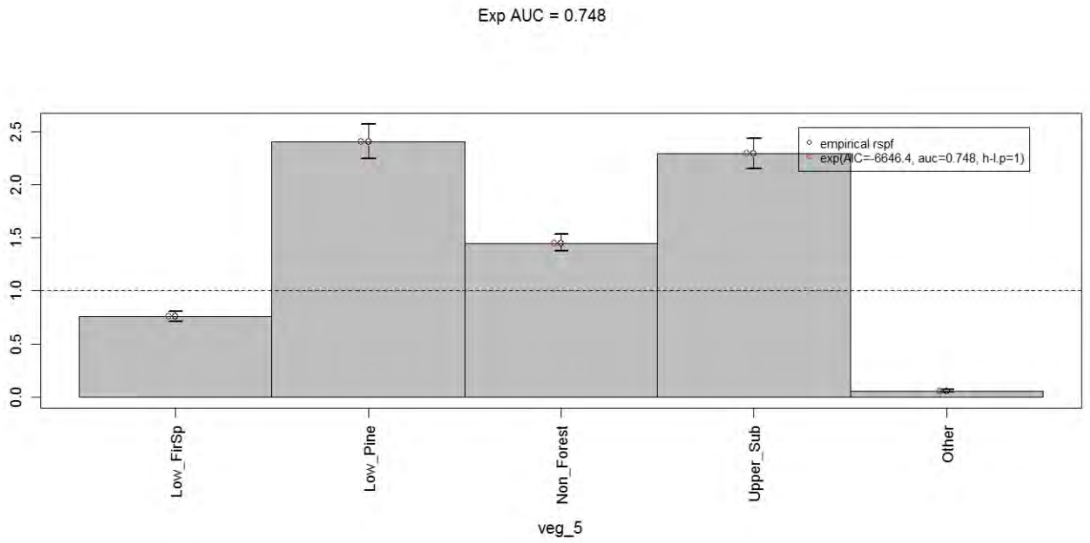


Figure 131. Tonquin caribou 71 selection for covariate Veg_5 during the late winter (January 22nd to May 22nd) season using the full final dataset (2002-2009).

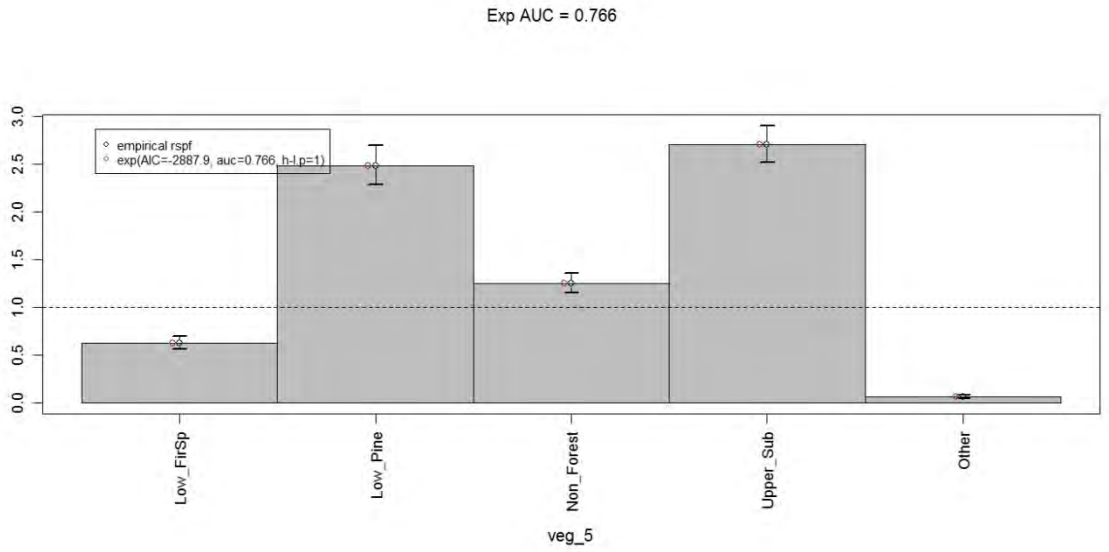
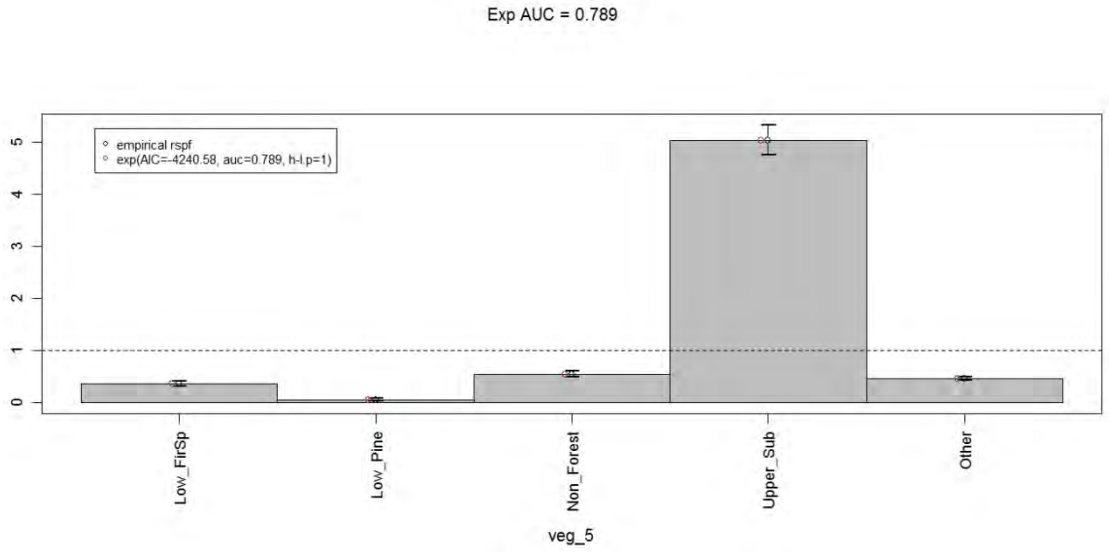


Figure 132. Tonquin caribou 101 selection for covariate Veg_5 during the late winter (January 22nd to May 22nd) season using the full final dataset (2002-2009).



6.3 Seasonal Wolf Models

6.3.1 Methods

We used methods described in 6.1 to develop summer and winter wolf habitat selection models for the Tonquin Range. We clipped all available GPS wolf collar locations within the Tonquin Range in winter (3,163 wolf locations, November 1st to May 22nd) and summer (3,609 wolf locations, May 23rd to October 31st) seasons using the beginning of the calving season and end of the rut as cutoffs. We used available locations queried for caribou habitat selection models.

Because of the large difference in the number of locations per animal (Tables 28 and 29), we conducted a post-hoc comparison of model covariates to compare sections of the data based on their influence on the final model. Specifically, in summer we compared the behavior of wolf 112 (from a resident pack) to wolf 120 (from a transient pack) as together they represent 79% of the data used to generate the habitat selection model. In winter, we compared wolf 120 to the remaining data available.

6.3.2 Results

In summer, distance to linear features was the strongest predictor of habitat selection (Tables 30 and 31). Wolves selected primarily for flat alpine areas close to streams and linear features. Secondly, wolves selected for east and south facing slopes of up to 15 degrees. In winter, wolves selected primarily for flat lower subalpine pine habitat at approximately 1500 m (Tables 32 and 33). Generally, north-facing slopes were avoided and selection for other aspects was similar at slopes up to 15 degrees. Selection for areas close to hiking trails was the second most important variable explaining wolf habitat selection after elevation.

Table 28. Available wolf locations used to develop summer (May 23rd to October 31st) resource selection models in the Tonquin range (2003-2011).

Animal ID	Num. Locations	Percent
18	37	1
56	314	9
57	245	7
58	53	1
63	95	3
112	1,658	46
120	1,175	33
121	32	1

Table 28. Available wolf locations used to develop winter (November 1st to May 22nd) resource selection models in the Tonquin range (2003-2011).

Animal ID	Num. Locations	Percent
18	45	1
27	27	1
40	85	3
56	432	14
57	24	1
58	33	1
62	11	0
63	114	4
81	274	9
112	535	17
120	1,570	50
121	13	0

Table 29. Forward stepwise selection of covariates during the summer season (May 23rd to October 31st) for Tonquin range wolves (2003-2011). Covariates are listed left to right in order of their explanatory strength. The best model has the lowest AIC score and is bolded.

Model	Dist Linear	Slope	Veg5	Aspect5	Dist Stream	AIC	AUC	VIF
1	X	X				-3725	0.77	1.0
2	X		X			-3543	0.78	1.9
3	X			X		-2468	0.73	1.6
4	X				X	-2815	0.74	1.0
5	X	X	X			-4537	0.80	1.9
6	X	X		X		-3952	0.78	1.6
7	X	X			X	-3868	0.78	1.2
8	X	X	X	X		-4797	0.81	2.0
9	X	X	X		X	-4658	0.81	1.9
10	**X**	**X**	**X**	**X**	**X**	**-4939**	**0.81**	**2.1**

Table 30. Coefficients and standard errors (SE) for Covariates in model 10 for the summer (May 23rd to October 31st) season for Tonquin wolves (2003-2011).

Covariate	Estimate	SE	*Z value*	*p*	VIF
(Intercept)	0.9850	0.1811	5.44	<0.001	NA
dist_linear_km	-0.3526	0.0142	-24.87	<0.001	1.2
Slope_deg	-0.0973	0.0040	-24.14	<0.001	1.5
veg_5Low_Pine	-0.5286	0.0860	-6.15	<0.001	1.5
veg_5Non_Forest	1.2623	0.0901	14.01	<0.001	2
veg_5Upper_Sub	-0.3335	0.0986	-3.38	<0.001	1.6
veg_5Other	-0.3209	0.0840	-3.82	<0.001	2.1
dist_stream_km	-0.8924	0.0860	-10.38	<0.001	1.2
aspect5East	0.8322	0.0772	10.78	<0.001	1.6
aspect5South	0.6141	0.0990	6.21	<0.001	1.5
aspect5West	-0.1116	0.0871	-1.28	<0.001	1.5
aspect5Flat	-0.6217	0.0984	-6.32	<0.001	1.5

Table 31. Forward stepwise selection of covariates during the winter season (November 1st to May 22nd) for Tonquin range wolves (2003-2011). Covariates are listed left to right in order of their explanatory strength. The best model has the lowest AIC score and is bolded.

Model	DEM	Dist linear	Aspect	slope	Dist Stream	AIC	AUC	VIF
1	X	X				-6611	0.85	1.0
2	X		X			-5460	0.81	1.7
3	X			X		-5044	0.81	1.3
4	X				X	-4679	0.80	1.1
5	X	X	X			-7487	0.87	1.7
6	X	X		X		-7065	0.86	1.3
7	X	X			X	-6692	0.86	1.1
8	X	X	X	X		-7601	0.87	1.7
9	X	X	X		X	-7524	0.87	1.7
10	**X**	**X**	**X**	**X**	**X**	**-7622**	**0.87**	**1.7**

Table 32. Coefficients and standard errors (SE) for Covariates in model 10 for the winter (November 1st to May 22nd) season for Tonquin wolves (2003-2011).

Covariate	Estimate	SE	*Z value*	*p*	VIF
(Intercept)	2.5940	4.6526	0.56	0.577	NA
DEM	-3.5171	0.1629	-21.59	<0.001	1.4
Dist_linear	-0.2994	0.0139	-21.59	<0.001	1.1
Aspect5East	1.5953	0.1729	9.23	<0.001	1.7
Aspect5South	1.6743	0.1959	8.55	<0.001	1.5
Aspect5West	1.9494	0.2038	9.56	<0.001	1.6
Aspect5Flat	1.7019	0.2024	8.41	<0.001	1.7
Slope_deg	-0.0336	0.0048	-7.02	<0.001	1.2
Dist_stream	-0.2570	0.0611	-4.21	<0.001	1.7

Figure 133. Tonquin wolf selection for covariate Dist_linear during the summer (May 23rd to October 31st) season using the full final dataset (2003-2011).

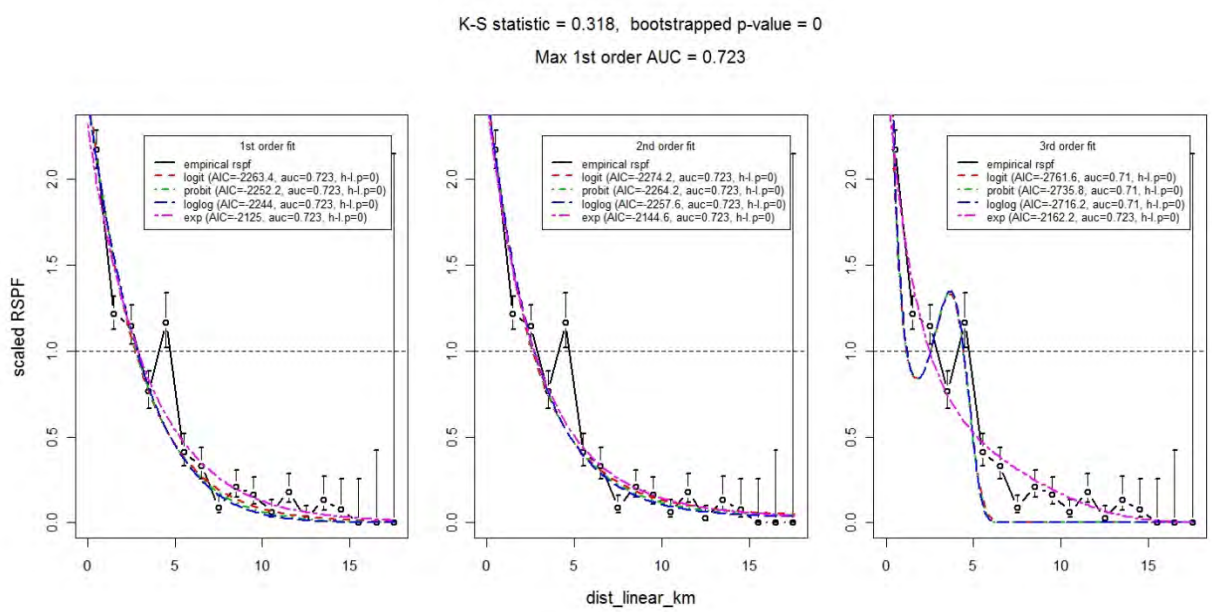


Figure 134. Tonquin wolf selection for covariate Slope during the summer (May 23rd to October 31st) season using the full final dataset (2003-2011).

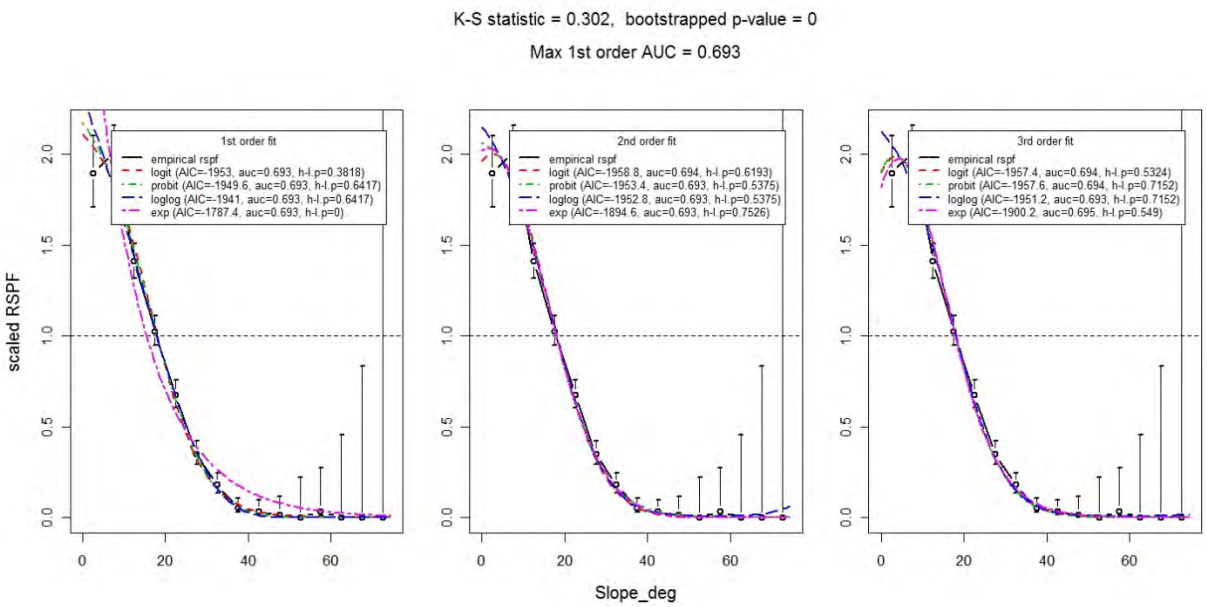


Figure 135. Tonquin wolf selection for covariate Veg_5 during the summer (May 23rd to October 31st) season using the full final dataset (2003-2011).

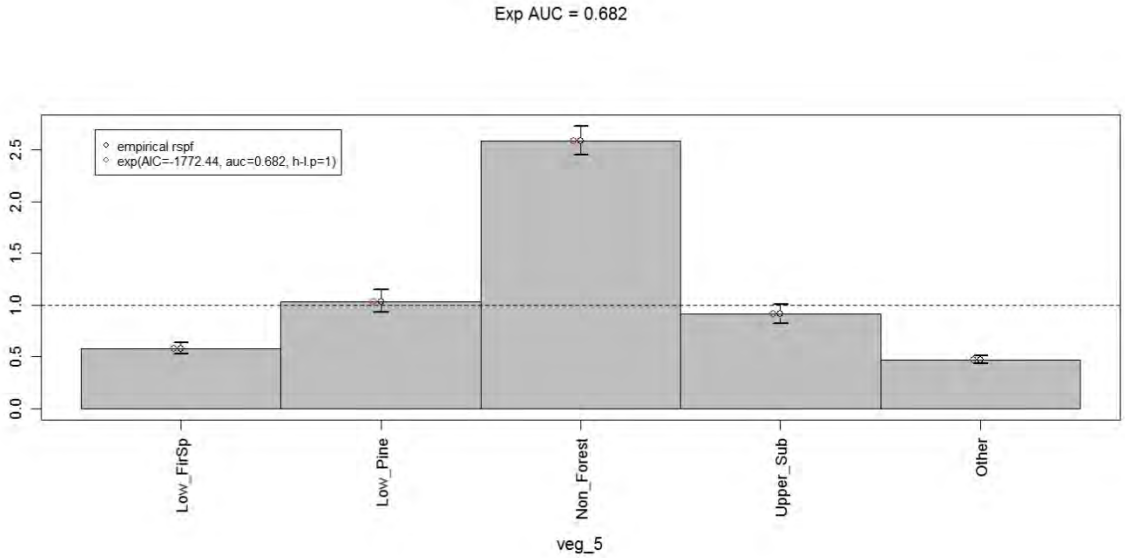


Figure 136. Tonquin wolf selection for covariate Aspect during the summer (May 23rd to October 31st) season using the full final dataset (2003-2011).

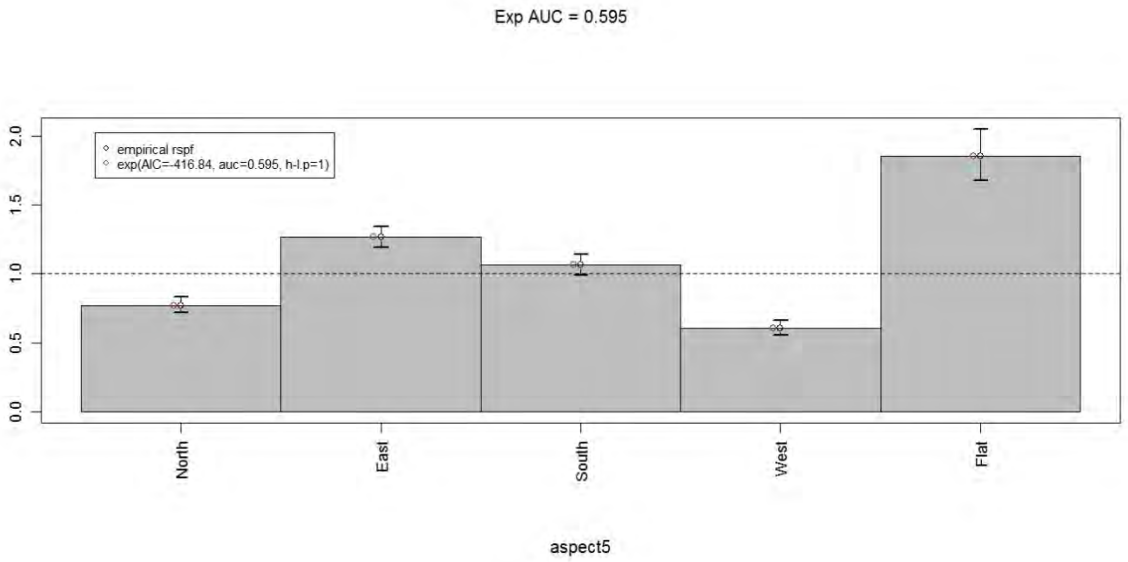


Figure 137. Tonquin wolf selection for covariate Dist_Stream during the summer (May 23rd to October 31st) season using the full final dataset (2003-2011).

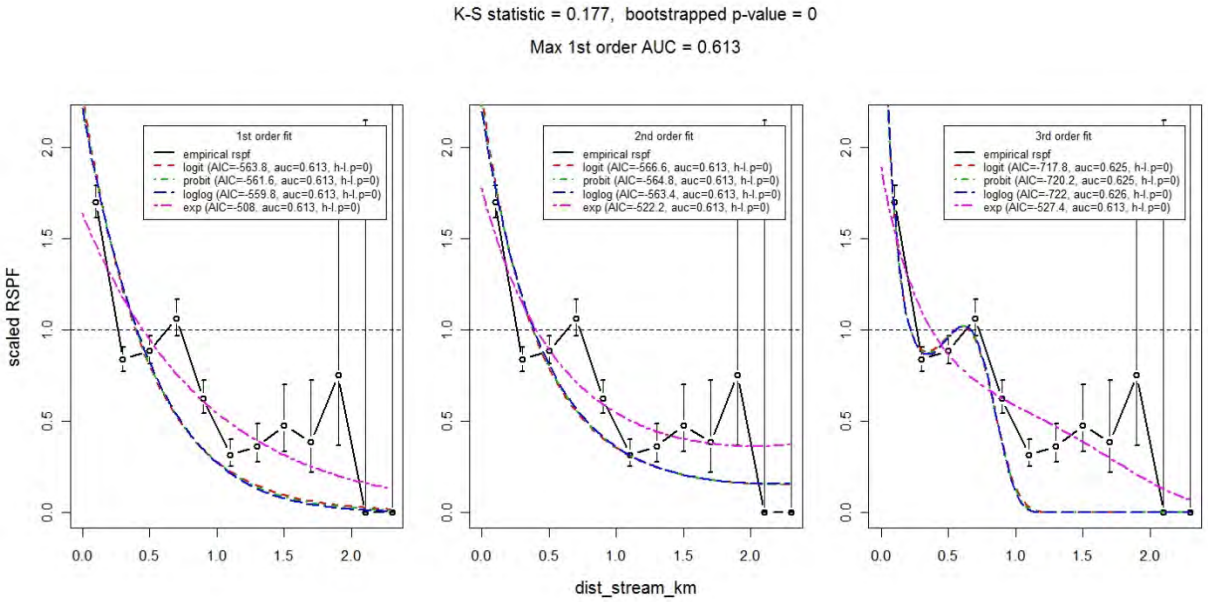


Figure 138. Tonquin wolf selection for covariate Elevation during the winter (November 1st to May 22nd) season using the full final dataset (2003-2011).

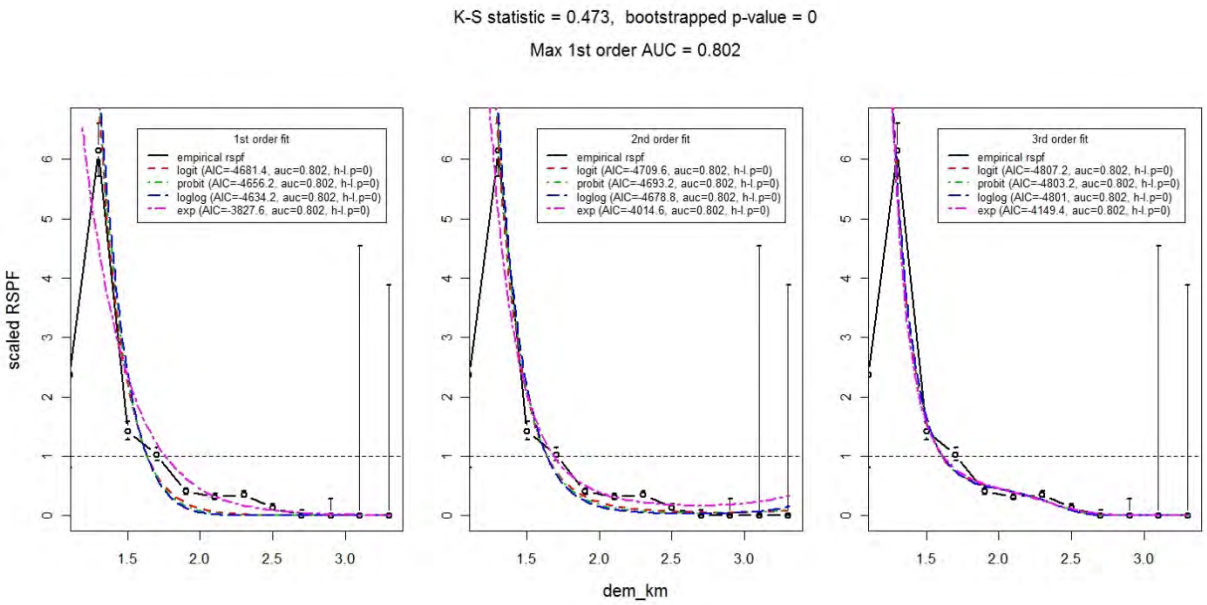


Figure 139. Tonquin wolf selection for covariate Dist_linear during the winter (November 1st to May 22nd) season using the full final dataset (2003-2011).

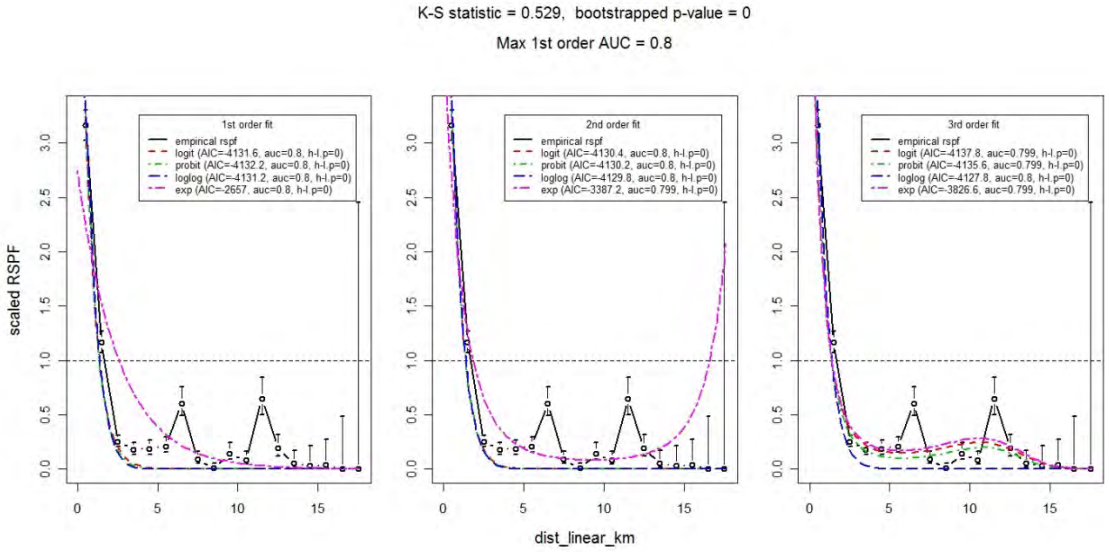


Figure 140. Tonquin wolf selection for covariate Aspect during the winter (November 1st to May 22nd) season using the full final dataset (2003-2011).

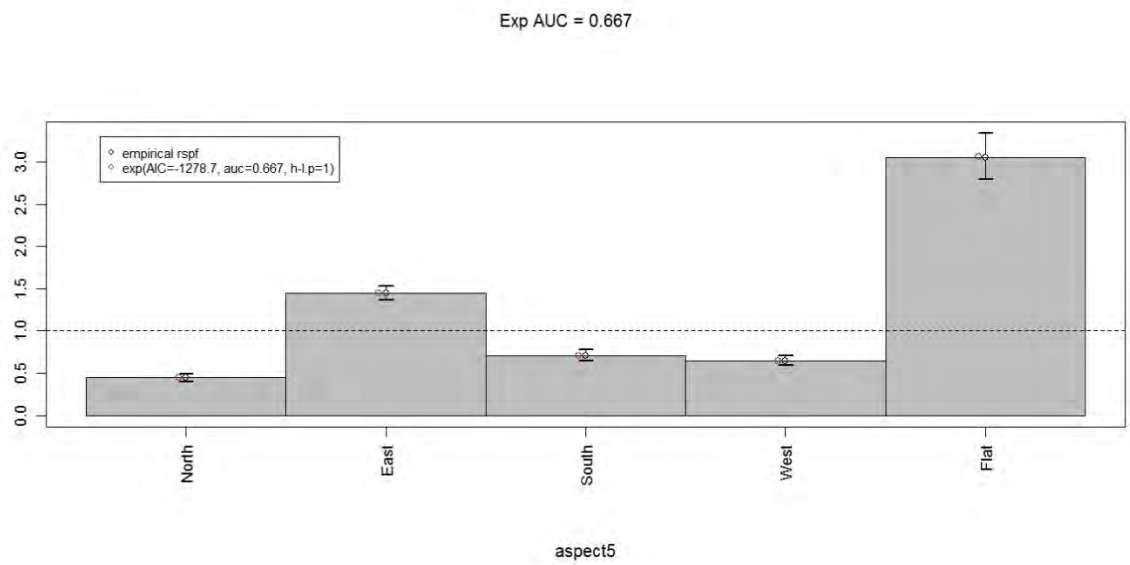


Figure 141. Tonquin wolf selection for covariate Slope during the winter (November 1st to May 22nd) season using the full final dataset (2003-2011).

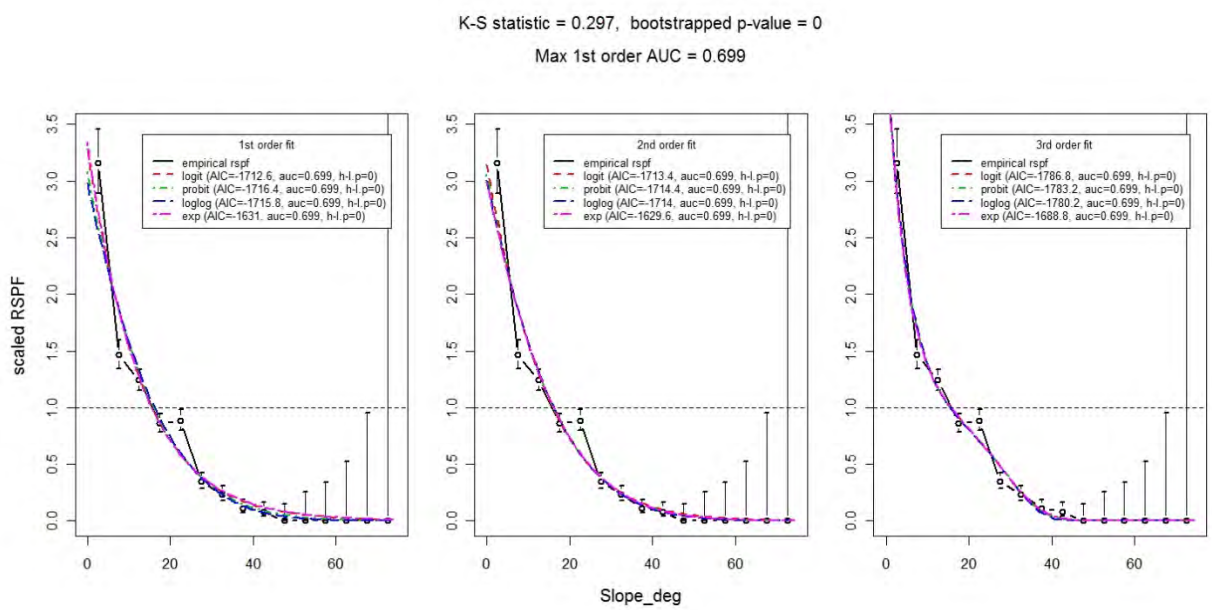
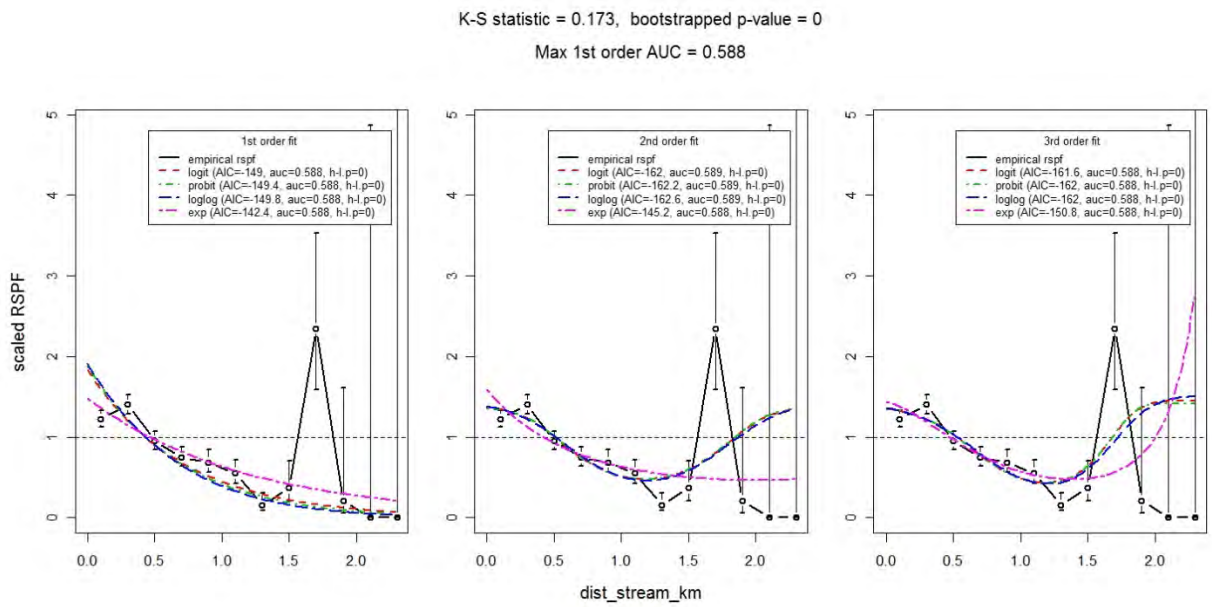


Figure 142. Tonquin wolf selection for covariate Dist_stream during the winter (November 1st to May 22nd) season using the full final dataset (2003-2011).



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