Assessing Caribou Survival in Relation to the Distribution and Abundance of Moose and Wolves

Annual Report March 2016

Prepared for the BC Oil and Gas Research and Innovation Society (BC OGRIS)

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Executive Summary

Our research is focused on quantifying the relationships among caribou, moose, and wolves across gradients of anthropogenic disturbances and moose and wolf densities. Here, we report on the first 12 months of that research. This project is using the fine-scale data provided by GPS monitoring to test hypotheses related to caribou resource selection and survival. During the reporting period, we received and analyzed moose GPS data. We developed screening tools and wrote scripts to allow the incorporation of new data into on-going analyses. Collar fix-rate success continues to show a seasonal pattern, which we believe is related to seasonal use of heavier cover by moose.

Some of the first steps in developing moose use/selection layers included identifying biologically relevant seasons, and identifying important vegetation cover types. Considering other published work, seasonal behaviours and environmental conditions for each species, and recognizing that these seasons needed to reflect potential changes in vulnerability to predation, we settled on 4 seasons (i.e., birthing: 16 May 16 – 15 July 15; late summer: 16 July – 31 October; early winter: 1 November – 31 January; and late winter: 1 February – 15 May). After obtaining the Ducks Unlimited (DU) Vegetation Layer (Ducks Unlimited Canada 2013), we re-classified the 30 DU vegetation classes in to 8 classes in accordance with the methods detailed by Demars (2015), but also tested the value of adding an additional class, marsh. Our examination suggests that the 8 classes used by Demars for boreal caribou, will also work across moose and wolf resource selection models.

We decided to model availability by using the 90th quantile of movement distances for each season. Using this metric, 12-h movements of collared moose appear longest during the birthing season (distinct from the actual parturition period) and shortest during early winter. We report use and availability estimates for habitat class, topographic (inclusive of elevation, slope and variation in slope) and various disturbance metrics. The relationship of moose to seismic and burns appears to vary across class, but further analyses will be necessary to determine if these relationships are significant.

While we continue to process existing caribou and wolf data, we used a subset of those data to contrast differences between wolf-caribou encounters and locations for collared, killed caribou. We used locations from 28 collared wolves and 104 collared caribou to identify nonlethal wolf-caribou encounters as defined by a wolf location being within 1971 m (mean 24-h caribou movement distance) of a caribou location within a 24-h period. Our preliminary results suggest that caribou are more likely to encounter wolves in flat areas near linear features and water. We did not, however, find that linear features increased the probability of mortality following an encounter and found that areas with large amounts of bogs and fens reduced the probability of being killed, but these analyses are ongoing.

Ultimately, our work is attempting to identify the drivers of caribou survival in the boreal with a particular interest in the direct and indirect effects of manageable anthropogenic activities. Specifically, we are interested in how development may alter risk via increased wolf search efficiency or apparent competition via changes in moose and wolf distribution or abundance, and how those interactions can be managed to reduce risk to caribou. In the coming year, we plan to utilize our moose resource selection and wolf risk models as covariates in modelling caribou survival. Those analyses will also include other landscape attributes, in order to examine these complex processes and interactions.

Project Overview and Objectives

Project Scope

Woodland caribou (*Rangifer tarandus*) are listed as threatened or of concern under the Species at Risk Act in Canada. Declining numbers of caribou have been linked to habitat alterations and to complex predator-prey interactions. Predators can disproportionately affect one prey species when those predators are numerically linked to another more abundant prey species (e.g., DeCesare et al. 2010; McLellan et al. 2010). This interaction has relevance to caribou on the boreal landscapes of northeast (NE) British Columbia (BC) because wolves (*Canis lupus*) are the principal predator of caribou, but moose (*Alces alces*) are the primary prey of wolves. Further, current patterns of landscape change in the boreal may be resulting in an increase in moose abundance and related increase in wolf abundance.

Our research is focused on quantifying the relationships among caribou, moose, and wolves across gradients of anthropogenic disturbances and moose and wolf densities — we are using the fine-scale data provided by GPS monitoring to test hypotheses related to caribou resource selection and survival. Our first step is to increase our understanding of the drivers of moose distribution and density, which will enable us to evaluate the spatial interaction between caribou and moose, and examine how this interaction changes under varying levels of disturbance. We will use a similar approach when developing wolf-risk layers, and ultimately, these layers in conjunction with both anthropogenic and natural disturbances (e.g., fire) will become covariates in our model of caribou survival to identify the attributes that affect the probability of caribou mortality.

Objectives

Using telemetry data from radio-collared moose, caribou, and wolves provided to UNBC, our moose-wolf-caribou interaction analysis will determine:

1. if moose distribution and abundance is related to human-caused habitat change inside and outside of core caribou habitat?;
2. if wolf use of caribou habitat is related to moose distribution and abundance?;

3. if predator and prey abundance and behaviour interact to put caribou at increased risk?; and
4. what biotic, landscape, and anthropogenic attributes affect the survival of boreal caribou — with particular reference to those attributes that can be managed?

Project Activities and Status for Year 1 of the Project

During the first year of this two-year project, we began work on all five proposed activities:

A1) receive and analyze moose telemetry data;

A2) develop initial moose use/selection layers (existing data);

A3) develop initial caribou risk layers using existing data;

A4) refine caribou risk layers using incoming moose, caribou, and wolf data; and

A5) conduct caribou survival analysis using all moose, caribou, and wolf data.

In this report, we address progress on activities 3 and 4 collectively, while all other activities are addressed separately.

Activity 1: Receive and Analyze Moose Telemetry Data

In mid-April 2015, we began receiving and processing moose telemetry data. Initially those data were provided directly to us by Caslys Consulting Ltd., but we are now downloading moose radio-collar data directly from the Vectronic Aerospace server; monthly collar summaries and potential mortality alerts continue to be provided to us by Caslys Consulting Ltd. Direct downloads of data from the server include all records sent via Globalstar link to Vectronic Aerospace. Because we need to be able to screen data and continually update our models as new data become available, we developed programs to evaluate and view locations (currently in Google Earth) shortly after each download. For most models of radio collars, there is often additional data stored on the collars that are not successfully uploaded via satellite link to the remote data server. To date, we have only been able to download a few recovered radio collars — all contained some additional fixes on the collar. During the second year of our project, we will continue to directly download any recovered collars (whether from moose, caribou or wolves) before those collars are either redeployed or sent in for refurbishment, and we will renew our efforts to directly download data from all radio collars retrieved from mortality investigations.

Collaring Approach and Distribution of Collars

Studies of habitat use and selection often restrict data collection to females. Our goal, however, is to understand how the presence of moose (likely through apparent competition) may influence the risk to boreal caribou. Male moose (i.e., bulls) may be selecting different landscape features than female moose (i.e., cows) at some times of the year (perhaps after the rut when male body condition is low). Therefore, if we only document locations of cows, and wolves are responding to the location and selection of bulls after the rut, we may miss important aspects of the interaction among moose, wolves, and caribou. Concurrently, we do not want to lose an emphasis on female moose, because information about calving and calf recruitment (from a combination of progesterone tests, movement data, and aerial observations of collared cows) may reveal another season when wolves select locations to target vulnerable individuals. Consequently, our target for deploying collars was one-third bulls and two-third cows, which we will try to maintain throughout the study.

Several factors could potentially influence the link between presence and risk to caribou through apparent competition. Such factors may include relative densities of moose, wolves, and caribou, and the extent of natural and anthropogenic disturbance on the landscape. In order to maximize the spread across the different gradients potentially affecting the interactions between moose, wolves, and caribou we chose to have moose collared in 3 areas: the Chinchaga RRA, Clarke Core, and Fortune Core in NE BC (see Figure 1).

Collar Deployment and Status

In March 2015, 38 moose were captured by Diversified Environmental Services (under contract from BC FLNRO) and affixed with Vectronic Aerospace VERTEX Survey Globalstar collars set to transmit individual locations twice daily at 0300 and 1500 GMT (Figure 1). Collared individuals were distributed in or in close proximity to the Chinchaga RRA (1 female; 3 males), Clarke Core (14 females; 4 males), and East Fortune Core (11 females; 5 males; Table 1). One male from the Fortune was killed by wolves immediately following capture and a female from the Clarke died in the spring during birthing. Three additional collars stopped transmitting locations in the spring and summer (see below).

During January 2016, 25 additional moose and the 3 individuals with failed collars were captured and affixed with new Vectronic Aerospace VERTEX Survey Globalstar collars set to transmit twice daily. Twelve females and 4 males were collared in the Chinchaga RRA. One female and 3 males were collared in the Clarke Core, and 3 females and 2 males were collared in the Fortune Core. One female collar was replaced in the Clarke Core, and 2 female collars were replaced in the Fortune Core. Five individuals succumbed to wolf predation this winter, including 2 recently collared males in the Chinchaga and Fortune. The other wolf-caused mortalities were 2 females from the Clarke and 2 from the Fortune (Table 1). The current distribution of collared moose achieves our desired spread across the Chinchaga RRA, Clarke Core, and East Fortune Core (Figure 1).

Direct Download of Failed Collars

Following the re-collaring of 3 moose with malfunctioning collars, data from each collar were directly downloaded to determine if the collars were still recording data, despite failing to transmit the data through the Globalstar satellite system. The collars did not store any locations past the last satellite transmission date, but an additional 26, 24, and 6 locations were gained from the 3 collars from before the last transmission date — it is likely that all recovered collars contain additional stored data and recovered collars should be directly downloaded whenever possible. The 3 malfunctioning collars were returned to Vectronic Aerospace (Berlin), but no additional data could be recovered from any of the collars. On all 3 collars, the GPS modules failed, but according to Vectronic Aerospace it was not possible to find the reason for the malfunction. Using the data from the direct download of those 3 collars, we also evaluated if there were any shifts in geographic coordinates of the transmitted locations in comparison to the downloaded locations, but found that the geographic coordinates were identical.

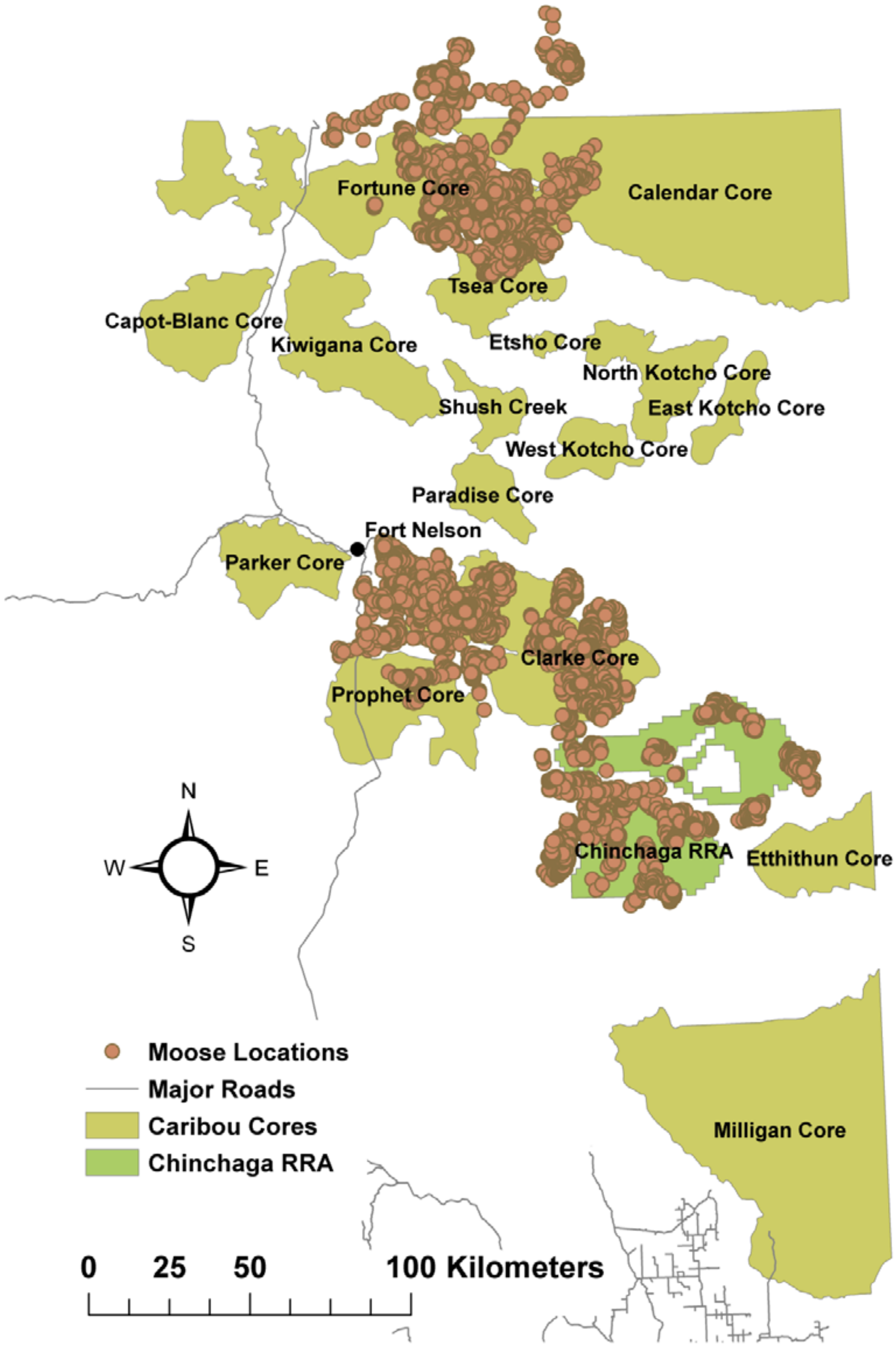

Figure 1. Distribution of moose telemetry fixes from March 2015 through February 2016. Bullets represent individual fixes for 62 (see Table 1) male and female moose (not including male killed soon after capture in March 2015).

Table 1. Current status and fate of GPS radio collars deployed in NE BC through March 2016.

Area	Collared		Mortality		In NWT		Failed GPS (Replaced)		Active	
	F	M	F	M	F	M	F	M	F	M
Chinchaga RRA	13	7		1					13	6
Clarke Core	15	7	3				1		12	7
Fortune Core	14	7	1	2		1	2		13	5

Development of Telemetry Screening Tools

There are several reasons to set-up software tools for rapid assessment of newly downloaded collar data, both to screen locations and to minimize the lag time between when mortalities occur and when they are detected. Therefore, we developed programs to quickly remove errant locations and monitor for behaviours potentially related to mortalities — we will focus on the latter.

As described above (and in Table 1), to date there have been 7 mortalities of collared moose during this study. In several cases, however, mortality site investigations lagged weeks behind the mortality. The VERTEX collars are programmed to send a mortality email alert (and concurrently switch the collar to send several fixes at 30-min intervals) if minimal movement occurs between several consecutive fixes, but there are other animal movement and collar performance patterns that may also be indicative of potential mortalities, warranting close monitoring or site investigation. Several such scenarios are listed in Table 2. For example,

Table 2. Potential anomalous collar signals and movements that could be associated with potential mortality events.

Move and Fix Scenarios
Abnormally long movement between consecutive fixes
Long collar movement followed by no fixes
Long collar movement followed by little subsequent movement
Many consecutive missed fixes
Many consecutive short movements

an abnormally long movement could be associated with an animal be chased by predators and a subsequent kill might place the collar in a position such that no fix can be received or transmitted for several days.

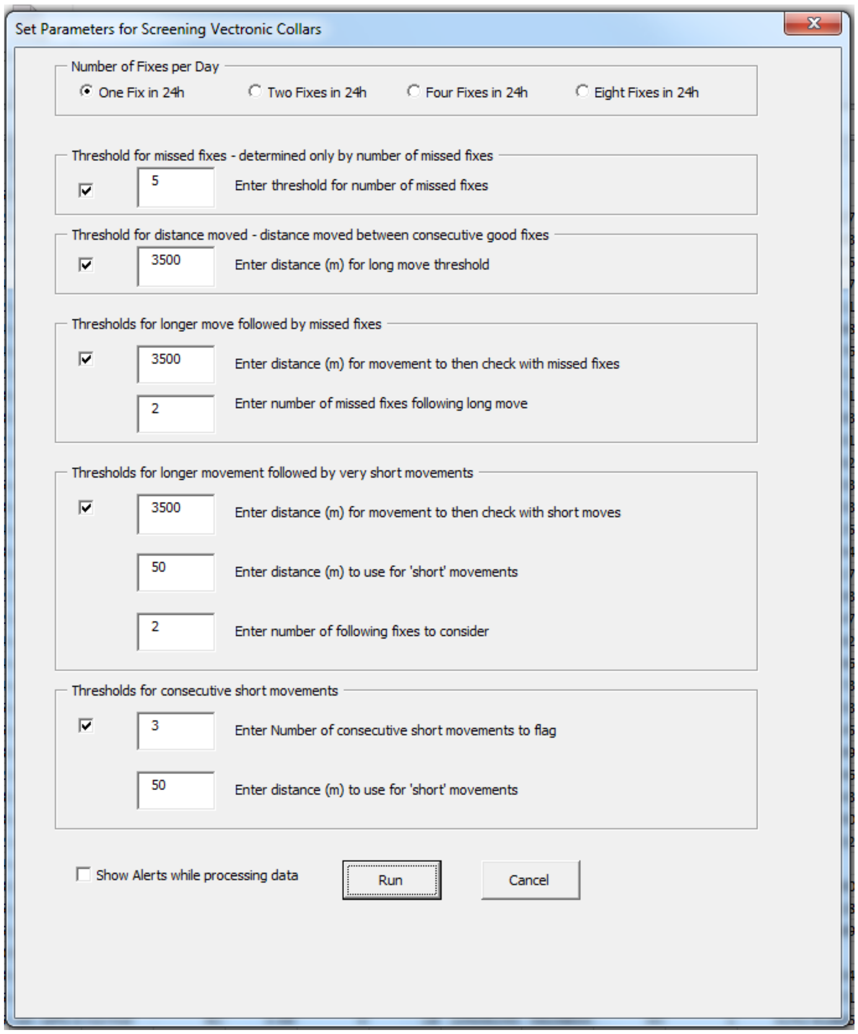

Figure 2. Screen capture of user-interface for screening Vectronic radio-collar downloads.

Consequently, we developed an Excel macro that flags the scenarios outlined in Table 2 by monitoring for rapid fixes (associated with mortality messages in case the actual message is not sent or received), tracks fix rate, and then produces individual KML (i.e., Google Earth Markup language) files for each downloaded moose. The interface for the program (Figure 2) allows

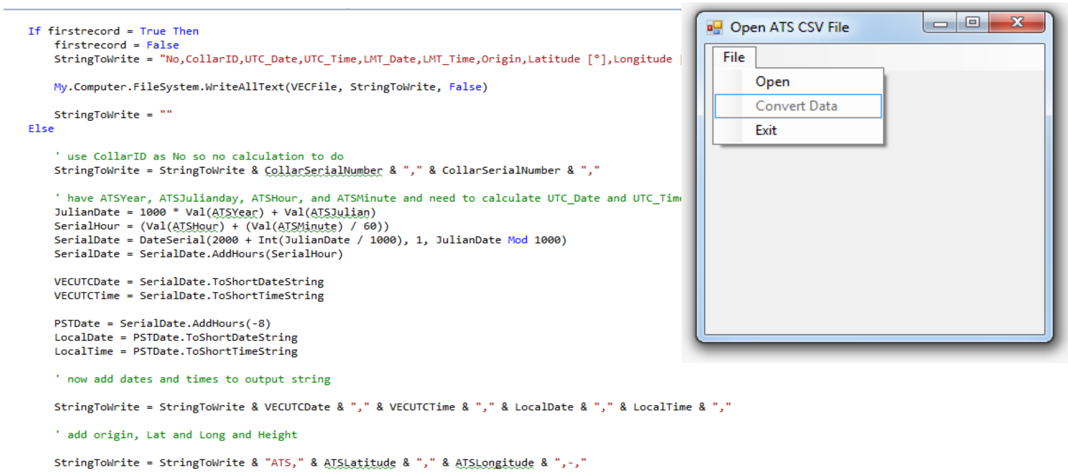

Figure 3. Screen capture of portion of program written to reformat ATS collar data into Vectronic collar format. Reformatted data can then be screened with the telemetry point screening program.

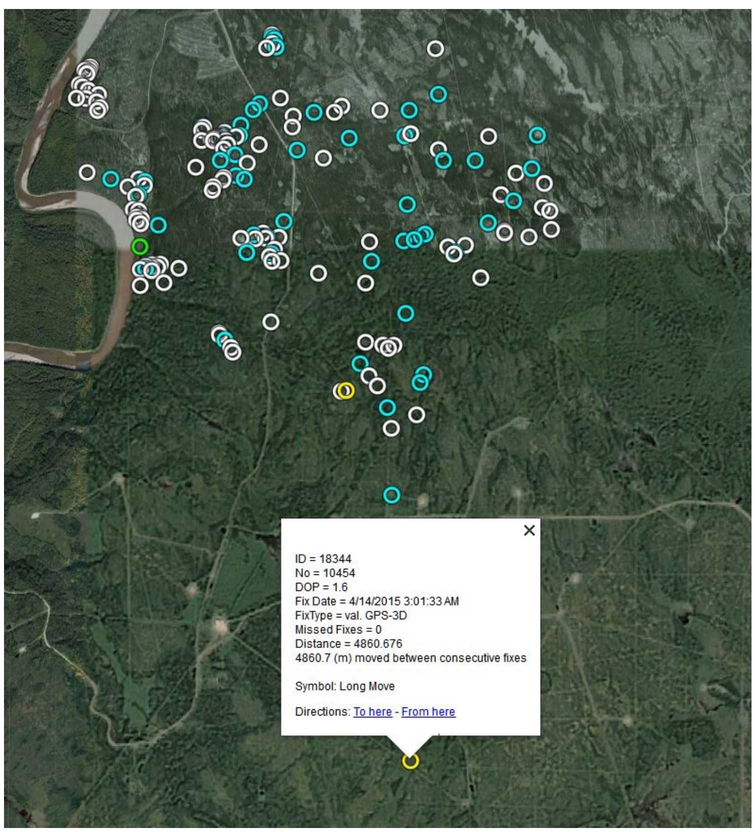

Figure 4. Portion of a KML file (viewed in Google Earth) for an individual collared moose. Different colour symbols are used to indicate long movements, missed fixes, and other scenarios (Table 2). Clicking on any symbol allows the user to view several attributes associated with that location.

customization of the screening criteria, and can also accommodate Advanced Telemetry Systems (ATS) GPS collar data by first using a separate reformatting program (Figure 3), which we have also written — we developed the ATS conversion because of work with a large number of ATS collars in a different study, but we have not extended this conversion to the native Lotek collar format[1]. Individual KML files are colour-coded for each type of flag (for moose) and document location attributes (see Figure 4). By using these combined tools, data can be quickly screened both by tabular inspection of flags and via examination of locations in Google Earth for anomalous (and potentially mortality related) movements.

Collar Fix Rate Success

Obtaining a high fix rate (high number of animal locations out of the possible number of locations) is important to ensure unbiased estimates of habitat use — if animals in habitats with high canopy coverage have lower successful acquisition of GPS locations, for example, then there can be a bias in estimates of habitat use. In our initial screening of data for fix rate success, we observed that the rate of successful fixes declined through September before improving from October onward (Figure 5). In addition, we also found that the average number of consecutively missed fixes had increased between March and September.

We proposed several hypotheses that might explain these trends including changes in the proportion of open habitats selected, an increase in movement distances between fixes, an on-average northward trend in animal locations affecting satellite dimensionality, and the influence of a few severely malfunctioning collars.

We performed several analyses to test our various hypotheses. To determine if ‘closed’ (canopy) habitats were impacting fix rate success, we reclassified the 30 vegetative classifications of the Ducks Unlimited Vegetation Layer (Ducks Unlimited Canada 2013) into open and closed habitats in accordance with classification descriptions provided with those data layers. We then tested if there was a relationship between individual monthly fix rates and the proportion of open habitats used. In addition, we looked for relationships between

[1] Caslys Consulting regularly provides us with wolf and caribou locations in a standard format (independent of collar type), and we do reformat those data so that they work with the KML screening tool.

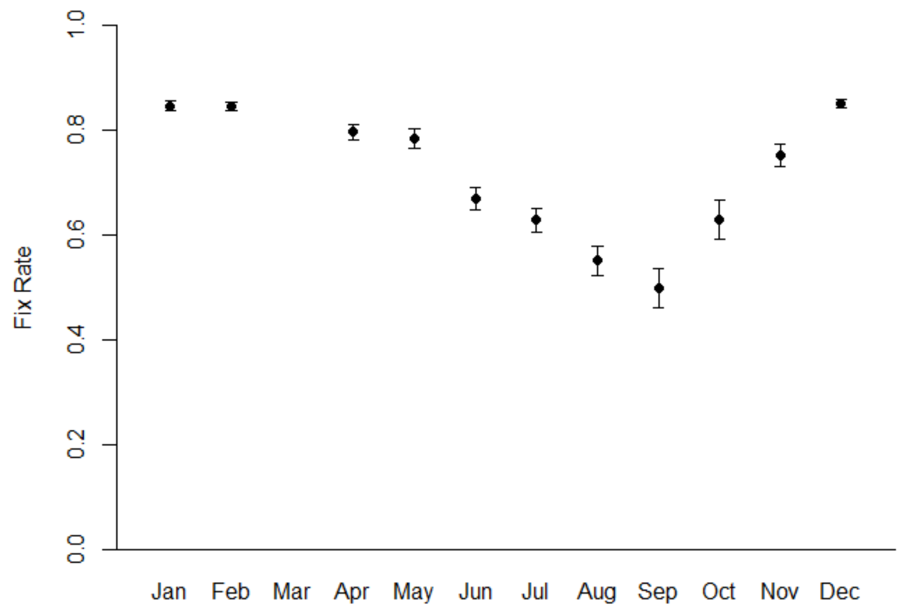

Figure 5. Mean (± SE) fix rate success (i.e., the proportion of possible fixes that were successfully recorded) as the study has progressed from April 2015 through February 2016. Data for March was excluded because animals where collared part way through March 2015 and data from March 2016 has not yet been processed.

individual monthly fix rate and the centroid of monthly fix latitudes for each moose and the average monthly consecutive-fix movement distance of each moose. We also visually evaluated monthly fix rate trends for each individual between March 2015 and September 2015. We did not detect any significant relationships between fix rate success and the proportion of open habitats used, latitudinal position, or movement distance, and overall, the majority of individuals were undergoing a similar moderate decline in fix rate over time. We did, however, observe that generally individuals that spent >70% of their time in open habitats in a given month appeared to have fewer low monthly fix rates. Recently, we conducted a similar analysis of the same model of collar that has been deployed in central BC for approximately 2 years. In those data, we see a similar drop in fix rate success during the summer months of both years followed by an increase in fix success during the fall and winter months. The most likely explanation appears to be that moose are likely spending more time in closed canopy areas in warmer months, which is leading to reduced fix rate success.

Activity 2: Develop initial moose use/selection data

Several actions during the first year of our work contributed to the development of our moose selection layer. Our first step was to define biologically relevant seasons that were applicable to each species. Next, we established a means of defining availability and generated random available locations. We then determined a suite of landscape attributes hypothesized to drive moose selection patterns. After assigning landscape attributes to 15,527 used and 77,635 available moose locations, we then explored attribute distributions for used and available locations in preparation for the development of resource selection models.

Determination of Seasons

Individual selection patterns of moose vary seasonally in conjunction with animal behaviours (i.e., birthing, rearing of young, breeding, etc.), nutritional needs, and food availability (Gillingham and Parker 2008). We thought it was important to define several biologically relevant seasons in order to identify differences in selection throughout the year. Establishing seasons for this project posed a unique problem, because the research includes 3 species with an overall objective of understanding how the interactions among moose, wolves and caribou influence caribou survival. Given this objective, we decided to establish identical seasons across species.

After consulting the work of other researchers, considering seasonal behaviours and environmental conditions for each species, and recognizing that these seasons needed to reflect potential changes in vulnerability to predation, we settled on 4 seasons (i.e., birthing, late summer, early winter, and late winter). Each species gives birth in the spring marking a period when the vulnerability of young moose and caribou calves potentially modifies the behavior of adult females. Ungulate calves serve as an abundant prey for wolves that are concurrently constrained by their own rearing of pups. Although both moose and caribou demonstrate a birth pulse around the beginning of June, we set our birthing period from May 16th to July 15th to capture the time when calves of both ungulate species are born until the time that the vulnerability of late-born calves (calves born in mid-June) has declined (calves reach ~1 month of age – Gustine et. al. 2006). This period also coincides with wolf pups becoming more mobile marking the beginning of our late summer season, which we defined from July 16^{th} until October 31^{st}. Late summer represents a snow-free season when young of the year are increasingly mobile and ungulate adults are maximizing consumption for the winter months ahead. Given the expectations of snow accumulation and ungulate body condition decline throughout winter, we thought it was important to define early and late winter seasons. We anticipated that early winter (November 1^{st} – January 31^{st}) would consist of moderate snow depths and relatively good ungulate body condition with the possible exception of mature ungulate males following the extensive energetic demands of the rut. We characterized late winter (February 1^{st} – May 15^{th}) as a period of increased snow depths and reduced ungulate body condition for both sexes.

Defining Availability

Availability has been defined in a variety of ways in resource selection studies (e.g., Latham et. al 2013; Johnson et. al. 2014). We chose to select a method that utilizes information on movement to characterize locations that were truly available to a given individual. For moose, we evaluated the distance moved between all 12-h consecutive locations and determined the 90^{th} quantile of movement distances for each season (Figure 6). In practice, we actually calculated the 90^{th} quantile movement distance for each individual moose by season (Figure 7). These values represent the 'normal' range of moose movement distances and therefore provide a means to define the area around each location from which a moose could have selected an alternative location. We buffered each moose location by the 90^{th} quantile movement distance for that individual during the corresponding season and then randomly selected 5 locations within the buffered area.

Procurement of Data Layers

A first step in understanding moose distributions is to determine the influence of vegetation type on moose use and selection. We signed an agreement with Ducks Unlimited Canada (hereafter DU) that allowed us to use their vegetation classification layer for the boreal region of British Columbia (Ducks Unlimited Canada 2013). Their classification of the boreal divides the region in to 30 classes. We re-classified these vegetation classes in to 8 classes in

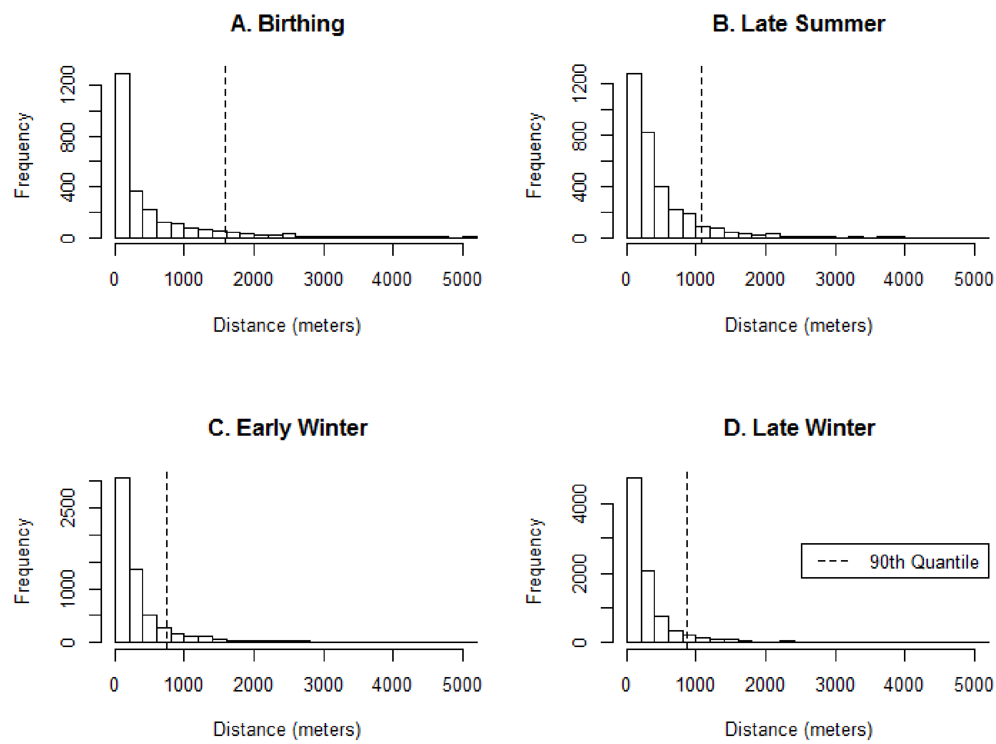

Figure 6. Frequency distribution of distances moved between consecutive 12-h fixes for all collared moose in NE BC by defined seasons.

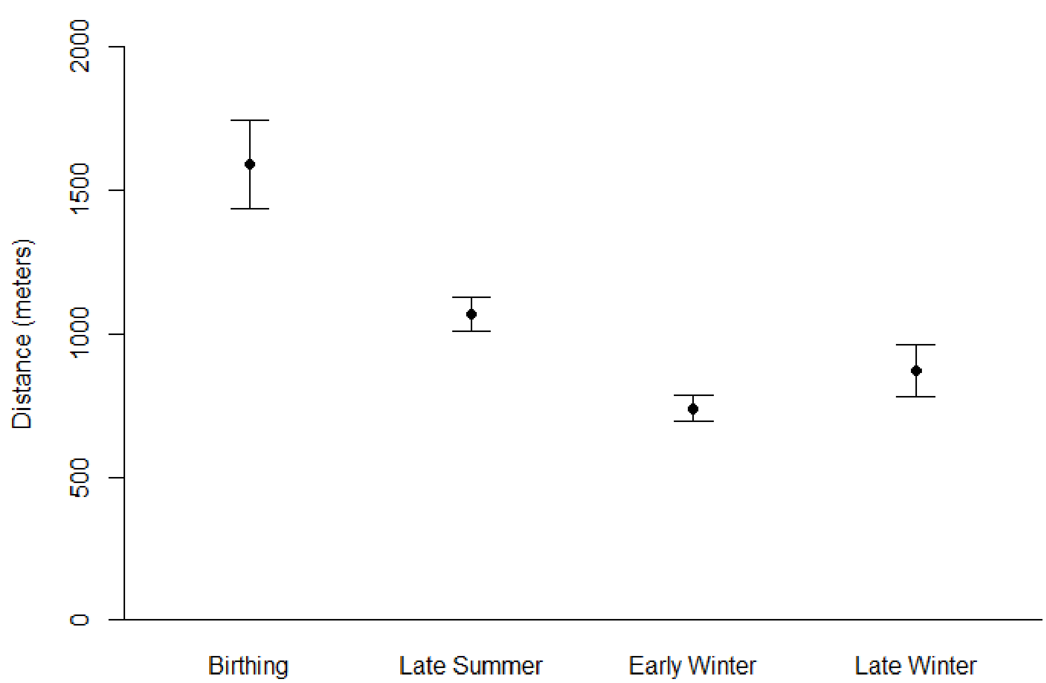

Figure 7. Mean (± SE) of the 90th quantiles of distances moved for each individual radio-collared moose in NE BC by season.

accordance with the methods detailed by Demars (2015) and also tested the value of adding an additional class, marsh. Our initial 9 classes included coniferous swamp, hardwood swamp, rich fen, poor fen, treed bogs, upland deciduous, upland conifer, marsh, and other, which contains several non-habitat or minimally present vegetative classes (e.g., open water, anthropogenic, etc.).

In addition, we downloaded layers from the BC Data Distribution Service and Oil and Gas Commission. We obtained fire layers, cutblock layers, and an elevation raster from the BC Data Distribution Service. From the Oil and Gas commission, we procured a suite of disturbance layers, including seismic, well site, and road layers.

Examination of Moose Use/Availability of Landscape Attributes

We estimated the proportion of moose locations found in each of the initial 9 vegetation classifications by season. We also estimated the availability of vegetation classes by taking 5 random locations from within the buffered area around each moose location with a radius set at the 90th percentile of movement distances for each individual by season. The 90th percentile movement is meant to represent potential movement between consecutive collar fixes eliminating unusually long movements, while acknowledging that frequent short consecutive movements may represent selection. Preliminary analyses suggest that moose may be selecting for hardwood swamp and avoiding bogs across all seasons (Figure 8). Further, it appears that moose may be avoiding conifer swamp in early and late winter and poor fens in late summer and early winter, but selecting rich fens in early and late winter (Figure 8). Although it may be possible that moose are selecting marsh during some seasons, we think that the influence of marsh is minimal, because of its rarity; therefore, we merged marsh with the ‘other’ vegetation class. For the remainder of the report and for all future analyses 8 vegetation classes will be included (consistent with Demars 2015).

We used our vegetation classes to generate several additional landscape attributes that could influence moose distributions. We were interested in evaluating if moose selected for areas near the transition areas (edges) between our 8 vegetation classes, so we calculated the distance to edge (Figure 9A) and the amount of edge within a 100-m buffer (Figure 9C) for all used and available locations. Given the high forage value of riparian areas and difficulty teasing apart their locations with the DU vegetation layer, we also calculated distance to water as a potential indicator of riparian areas, by separating out and calculating the nearest distance to one of the 3 water classes (Figure 9B) contained in the original 30 DU vegetation classes.

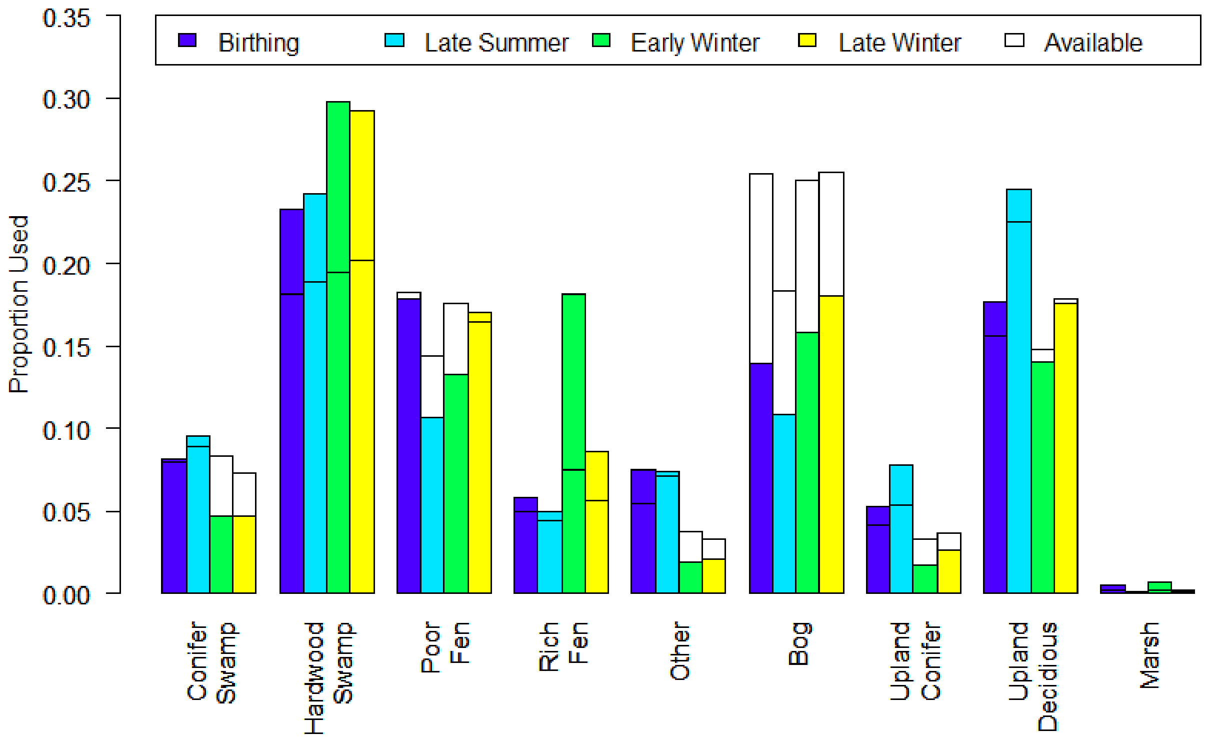

Figure 8. Seasonal use and availability of 9 habitat classes (see text) by collared moose in NE BC. Each bar represents the use of that habitat class in a specific season with an overlapping transparent bar that represents the proportion of available habitat as determined from random locations within a buffer around each used location (see text for details).

Lastly, we calculated a Shannon diversity index (Shannon and Weaver 1963) of the vegetative classes within 100 m of each used and available location (Figure 9D). The data suggest that although moose appear to be selecting for areas closer to edges (Figure 9A), they do not select for areas with increased length of edge (Figure 9C) or areas with increased vegetation class diversity (Figure 9D). We also see that moose seem to be selecting areas closer to water, although a formal assessment of selection will be necessary to validate these inferences.

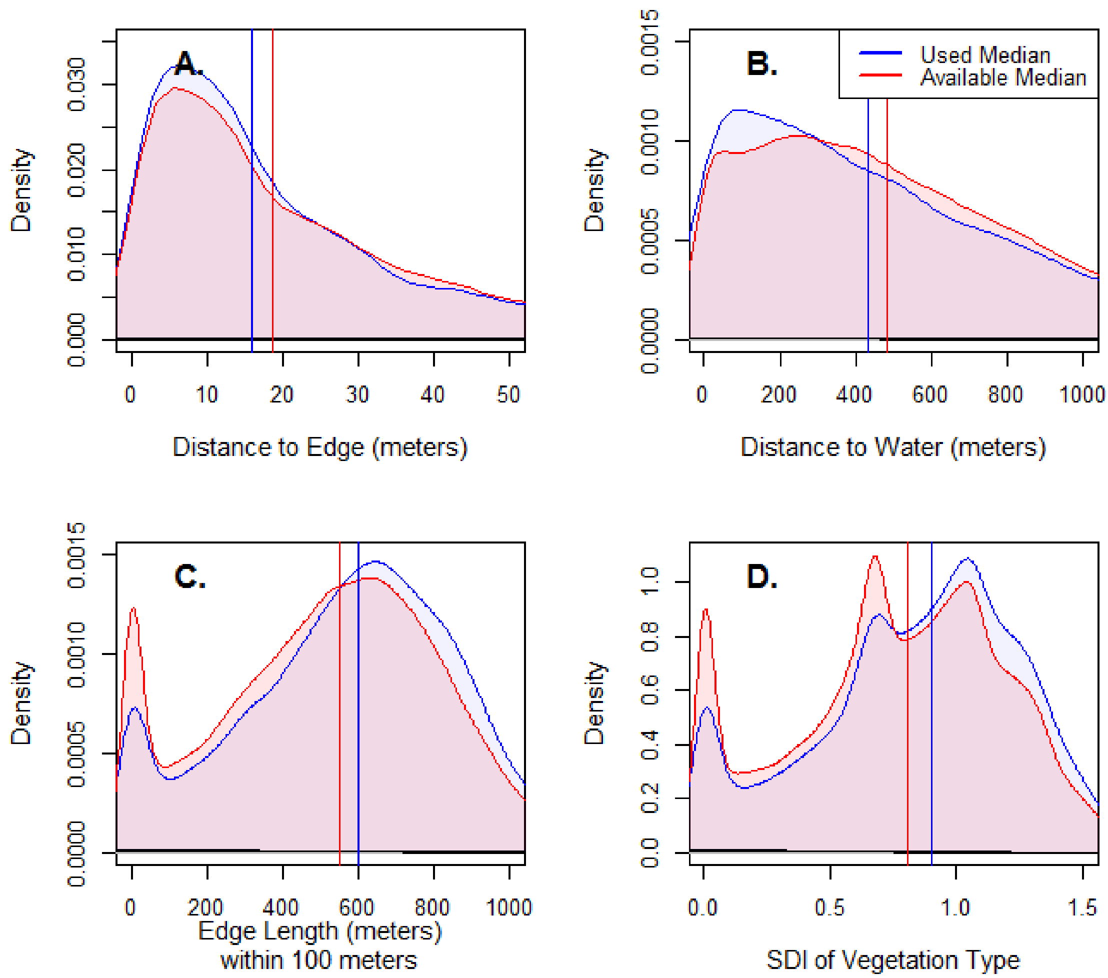

Figure 9. Comparison of Use (area under blue curve) and Availability (area under red curve) for moose GPS locations compared to random locations (see text) for distance to edge (A), distance to water (B), total length of edge within 100 m (C), and a Shannon Diversity Index (SDI) of vegetation classes within 100 m (D).

We used the downloaded elevation raster to generate slope, standard deviation (SD) of the slope within 100 m (terrain roughness – Grohmann et. al. 2011), northness, and eastness layers (sensu Gillingham and Parker 2008). The influence of elevation on moose distribution appears minimal (Figure 10A), which is not surprising given the small range of elevation values in the boreal of northeast BC. There does seem, however, to be some limited support for moose selecting steeper slopes (Figure 10B) and rougher terrain (Figure 10C).

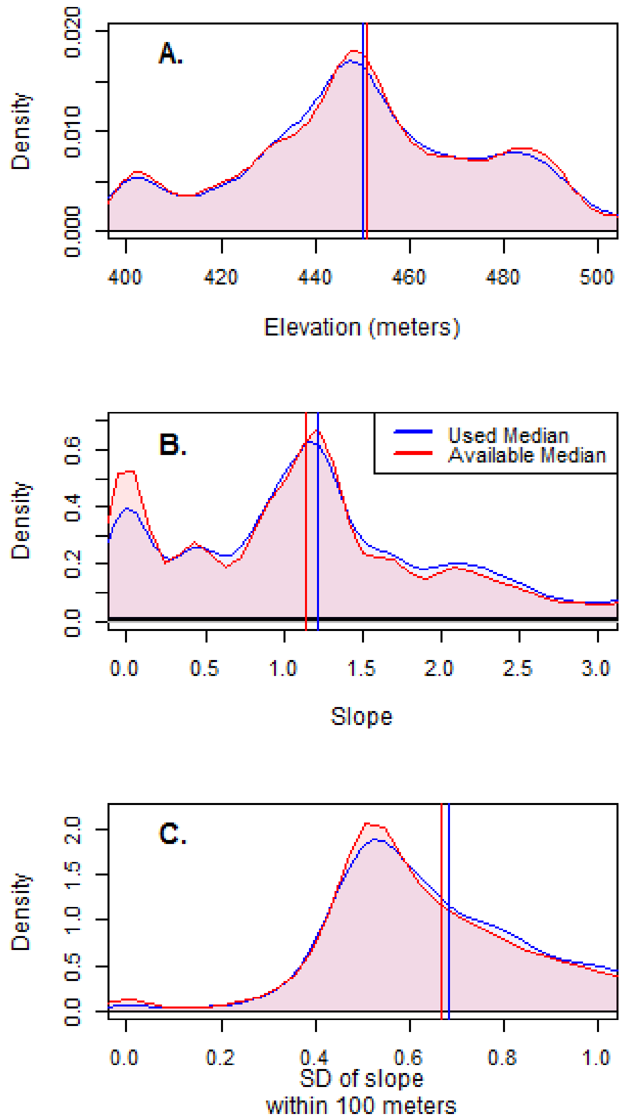

Figure 10. Comparison of Use (area under blue curve) and Availability (area under red curve) for moose GPS locations compared to random locations (see text) for elevation (A), slope (B), and the standard deviation (SD) of slope with 100 m as an index of terrain roughness (C).

Fire, cutblocks, and natural gas development all represent disturbances in the boreal. We were interested in understanding how seismic lines and roads are potentially used as travel corridors by moose and/or as early seral foraging sites. We calculated the distance to seismic and the length of seismic within 100 m of used and available locations. We used the same approach for roads. Fires and cutblocks may also provide moose with early seral foraging opportunities. After reviewing successional literature in the boreal and elsewhere, we decided to separate areas with burns ≤30 years old from older burns and unburned areas. Although some vegetation classes (treed bogs) in the boreal will likely not recover within 30 years of a burn, we did not consider these classes to be frequently used moose habitats and were more interested in understanding how burns may impact foraging opportunities in areas commonly used by moose (uplands and swamps). We also set a ≤30 year cut-off for cutblocks and then calculated the area burned and the area cut within 100 m of each used and available location. Given that we thought the relationship of moose selection and disturbance may vary between vegetation classes, we examined use and availability for 2 of these attributes across vegetation classes (Figure 11). The relationship of moose to seismic and burns appears to vary across class, but further analyses will be necessary to determine if these relationships are significant.

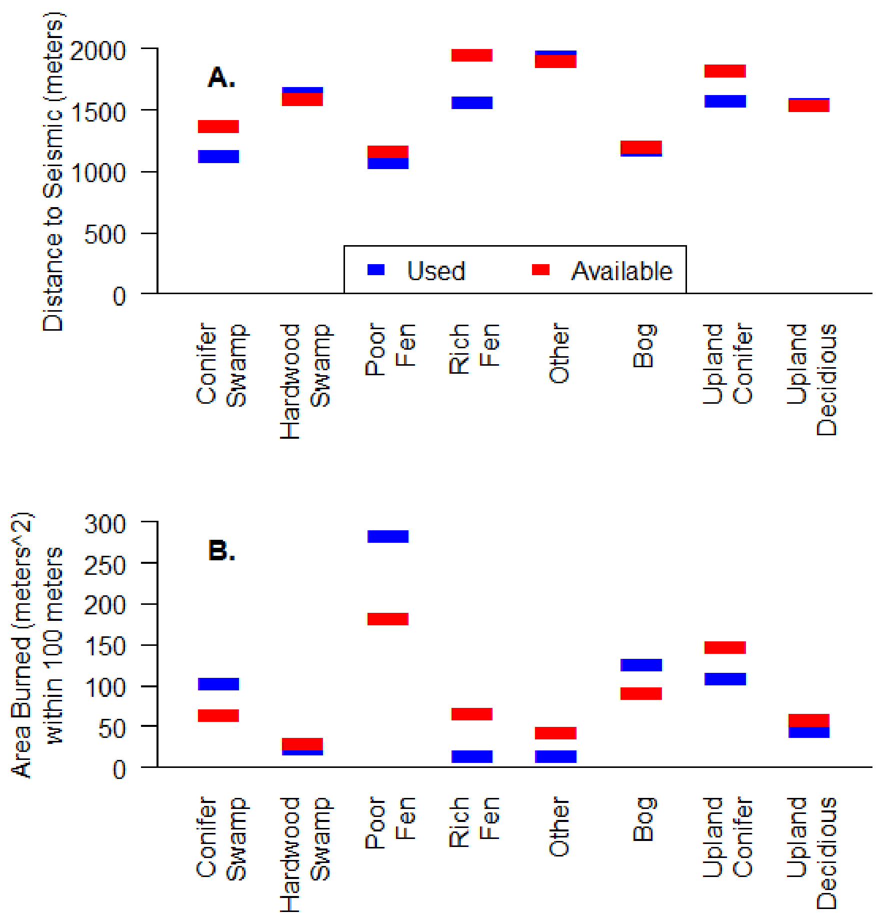

Figure 11. Comparison of Use (blue bars) and Available points (red bars) for moose GPS locations compared to random locations (see text) for distance to seismic (A) and area burned within 100 m of a location (B) by vegetation class.

Assessment of Caribou Core Attributes and Moose Density

The scale at which apparent competition may occur or is exacerbated also warrants further study. Disturbances such as fire or natural gas development may alter moose distributions leading to increased overlap between moose and wolves with caribou, subsequently leading to decreased caribou survival. Alternatively, disturbances may alter moose densities leading to increased moose and wolf population sizes, which may also result in decreased caribou survival. In the aforementioned analyses, we are developing methods to evaluate the drivers of moose distributions, but we think it is equally important to examine potential drivers of moose density. To that end, we performed a preliminary vegetation class analysis to assess if vegetation class proportionality alone is a good predictor of current moose densities across caribou cores. We also calculated the area burned within each caribou core and the amount of disturbance of each core by buffering a combined roads layer by 500 m (Environment Canada 2012; Table 3). We are currently exploring these relationships while also adding additional core attributes that may be important moose density indicators.

Table 3. Proportion of each Caribou Core area that is comprised of the 8 vegetation classes.

Caribou Core	Fire	Disturbance	Treed Bogs	Rich Fen	Poor Fen	Upland Conifer	Upland Deciduous	Hardwood Swamp	Conifer Swamp	Moose per km^2 ‡‡
Calendar	0.1	0.6	0.4	0.0	0.3	0.0	0.0	0.065	0.1	0.018
Capot-Blanc	0.0	0.4	0.3	0.0	0.2	0.0	0.2	0.138	0.1	0.076
Chinchaga-RRA	0.0	0.3	0.3	0.1	0.2	0.0	0.1	0.186	0.1	0.151
Clarke	0.2	0.5	0.4	0.1	0.1	0.0	0.1	0.197	0.1	0.145
Etthithun	0.0	0.6	0.2	0.1	0.2	0.2	0.1	0.093	0.1	0.044
Fortune	0.0	0.3	0.4	0.1	0.2	0.0	0.1	0.149	0.0	0.046
Kiwigana	0.0	0.3	0.4	0.1	0.2	0.0	0.1	0.158	0.0	0.159
Kotcho	0.4	0.6	0.4	0.0	0.3	0.0	0.0	0.080	0.1	0.127
Milligan	0.2	0.8	0.1	0.2	0.3	0.2	0.1	0.031	0.1	0.113
Paradise	0.1	0.4	0.2	0.1	0.3	0.0	0.1	0.161	0.2	0.124
Parker	0.1	0.4	0.2	0.0	0.3	0.1	0.1	0.058	0.1	0.246
Prophet	0.1	0.4	0.1	0.0	0.4	0.1	0.1	0.101	0.1	0.121
Tsea	0.0	0.6	0.3	0.0	0.4	0.0	0.0	0.145	0.1	0.172

‡‡ Density estimates were obtained from McNay et al. 2013 and Thiesen 2010.

Activity 3 and 4: Develop and Refine Caribou Risk Layers with Moose, Caribou, and Wolf Data

Predation risk can be characterized as the joint probability of encountering a predator and the probability of being killed by a predator following an encounter (Hebblewhite et. al. 2005). Frequently, researchers model predator resource selection as an index of risk. This may be a reasonable approximation of risk for a primary prey species if we assume that the importance of the probability of encounter far outweighs the probability of being killed following an encounter. In the boreal, caribou are an alternative prey species for wolves, and as a result, the 2 species demonstrate different habitat selection (Latham et al. 2013), which reduces the likelihood that a wolf resource selection model alone will be a good indicator of predation risk for caribou.

Given the various aspects of risk and the uncertainty of which approach is most appropriate to approximate risk for boreal caribou, we are in the process of developing several risk layers that will be tested against used and available caribou locations to identify the risk layer that best describes how caribou perceive risk. We plan to build wolf resource selection models as an index of the probability of encountering a wolf. We have already screened and assigned landscape attributes for 22,752 used and 113,760 available wolf locations (Table 4) and will begin modelling wolf resource selection once we complete our resource selection models for moose, which will be an additional covariate in the wolf model.

As an alternative approach to modeling the probability of encounter, we have identified wolf-caribou encounters using wolf and caribou locations and have conducted a preliminary analysis on what landscape attributes predict the caribou locations where wolves are more likely to be encountered. We have screened and assigned landscape attributes for 98,826 used and 494,130 available caribou locations (Table 4). We also have compared these wolf-caribou encounters with caribou mortality sites assigned to wolves to identify the locations where caribou are killed versus where they are encountered by wolves. Ultimately, these 3 approaches to risk will be tested against used and available caribou locations to determine which layer best approximates risk.

Table 4. The number of individual collared wolves and caribou with location data and the number of locations by core.

Core	Individual Wolves	Locations	Individual Caribou	Locations
Calendar	0	0	15	15694
Capot-Blanc	0	0	2	3489
Chinchaga RRA	0	0	11	9183
Clarke	10	7461	6	5734
Kiwigana	0	0	10	4815
Kotcho	2	1823	11	12332
Etthithun	0	0	2	1403
Fort Nelson	4	2703	5	4461
Fortune	3	4712	12	7834
Milligan	1	115	18	18487
Paradise	5	2030	0	0
Parker	1	422	3	4916
Prophet	0	0	4	3640
Tsea	2	3486	2	2950
Outside Cores	0	0	3	3888
Totals	28	22752	104	98826

Data Screening

This project presents a unique challenge by providing a large amount of existing data, while also requiring the rapid screening and analysis of continually collected data. To combat the challenge of screening data and meeting project objectives in a timely manner, we have written a program in program R (R Development Core Team 2014) to rapidly screen caribou and wolf location data. This program first utilizes a separate file containing collaring dates for each individual wolf or caribou so that locations prior to collaring or after mortality can be removed. Next, the program calculates movement rates between fixes for each individual wolf and caribou and then calculates the 95th quantiles across all movement rates for each species by season. The 95th quantile is used to flag long movements that may be indicative of errant fix locations. We used movement rates instead of movement distances, because of variability in fix rate settings between collars. The 95th quantile was selected as a means of flagging movement rates we deemed as unusually rapid (top 5% of movement rates). The R program works in conjunction with an adapted version of the moose macro to produce an individual KML file for each individual (Figure 12). Locations are colour-coded by season and rapid movements are flagged and contain additional attributes allowing for visual examination of long distance movements and the deletion of errant fix locations, when necessary.

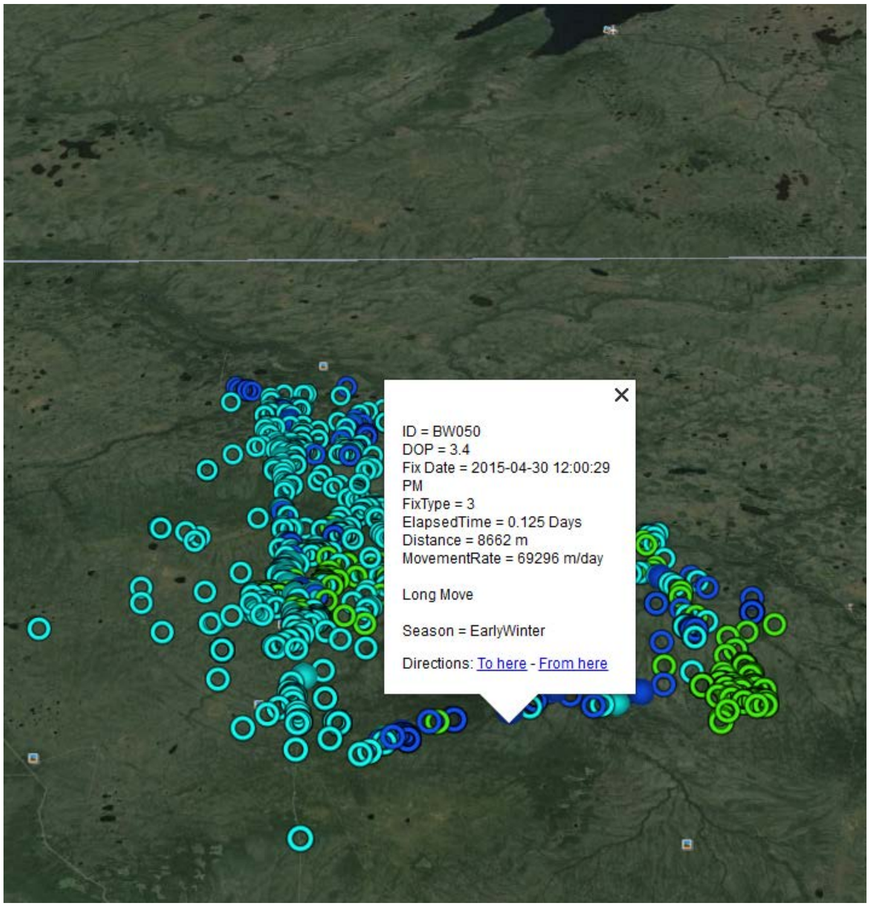

Figure 12. Portion of a KML file (viewed in Google Earth) for an individual collared wolf. Different colour symbols are used to indicate seasons, while filled circles indicate rapid movements (>95th quantile of seasonal movement rate). Clicking on any symbol allows the user to view several attributes associated with that location.

Following the removal of errant fixes, we determined that it was necessary to thin the data for each individual to a constant fix rate for each season and estimate the availability. A variety of different collars have been used throughout the study and were set to transmit fixes at a variety of fix intervals (5-min, 30-min, 1-h, 3-h, 6-h, 11-h, 12-h, 13-h, 23-h, and 24-h) that further changed throughout the year. The R program imports a file that contains set intervals for each individual by season to assure consistency between seasons and some level of independence between consecutive locations (all intervals ≥3 h). Finally, the program calculates quantiles of distances moved for consecutive wolf locations for each season and consecutive caribou locations for each season (Figure 13) to be used during the determination of availability in the same manner as described for moose. We used a reduced the quantile (80th) for wolves because of the propensity of wolves to on occasion move extremely long distances (>20 km) between consecutive fixes, but maintained the same quantile for caribou (90th) as used for moose when determining availability. Currently, we have processed locations from 28 collared wolves primarily from the northern half of the study site (Table 4; Figure 14) and 104 collared caribou from across NE BC (Table 4).

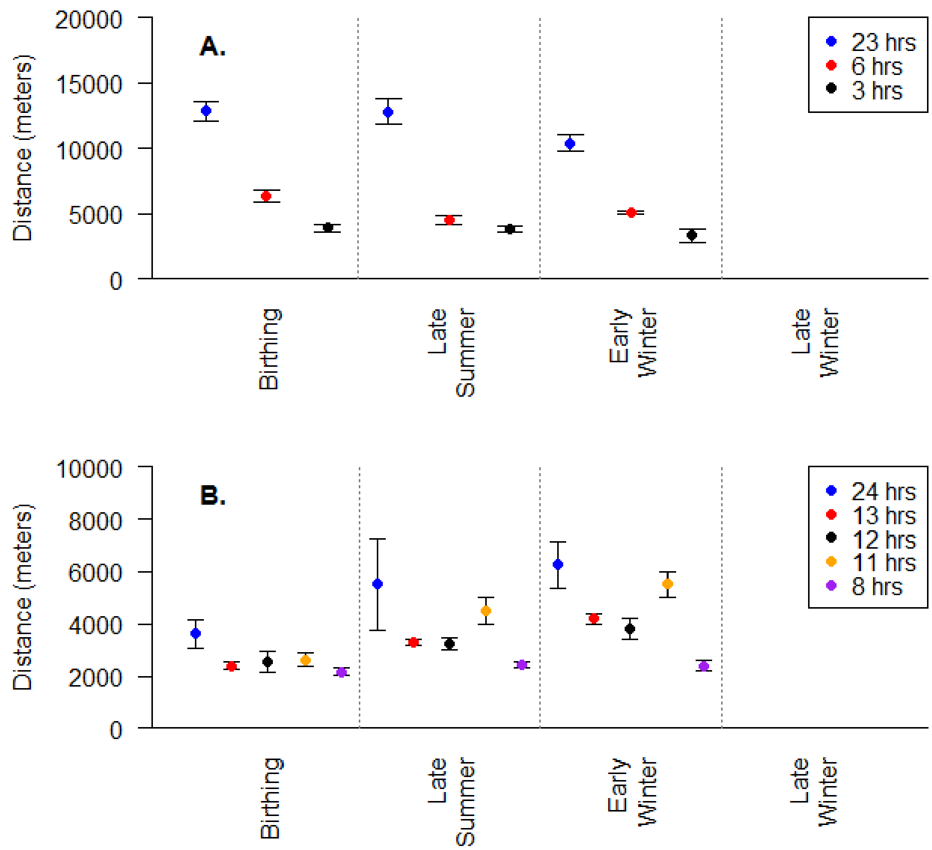

Figure 13. Mean (± SE) of the 80th quantiles for wolves (A) and the 90th quantiles for caribou (B) of distances moved for each individual by interval and season in NE BC. Late winter quantiles have not been completed.

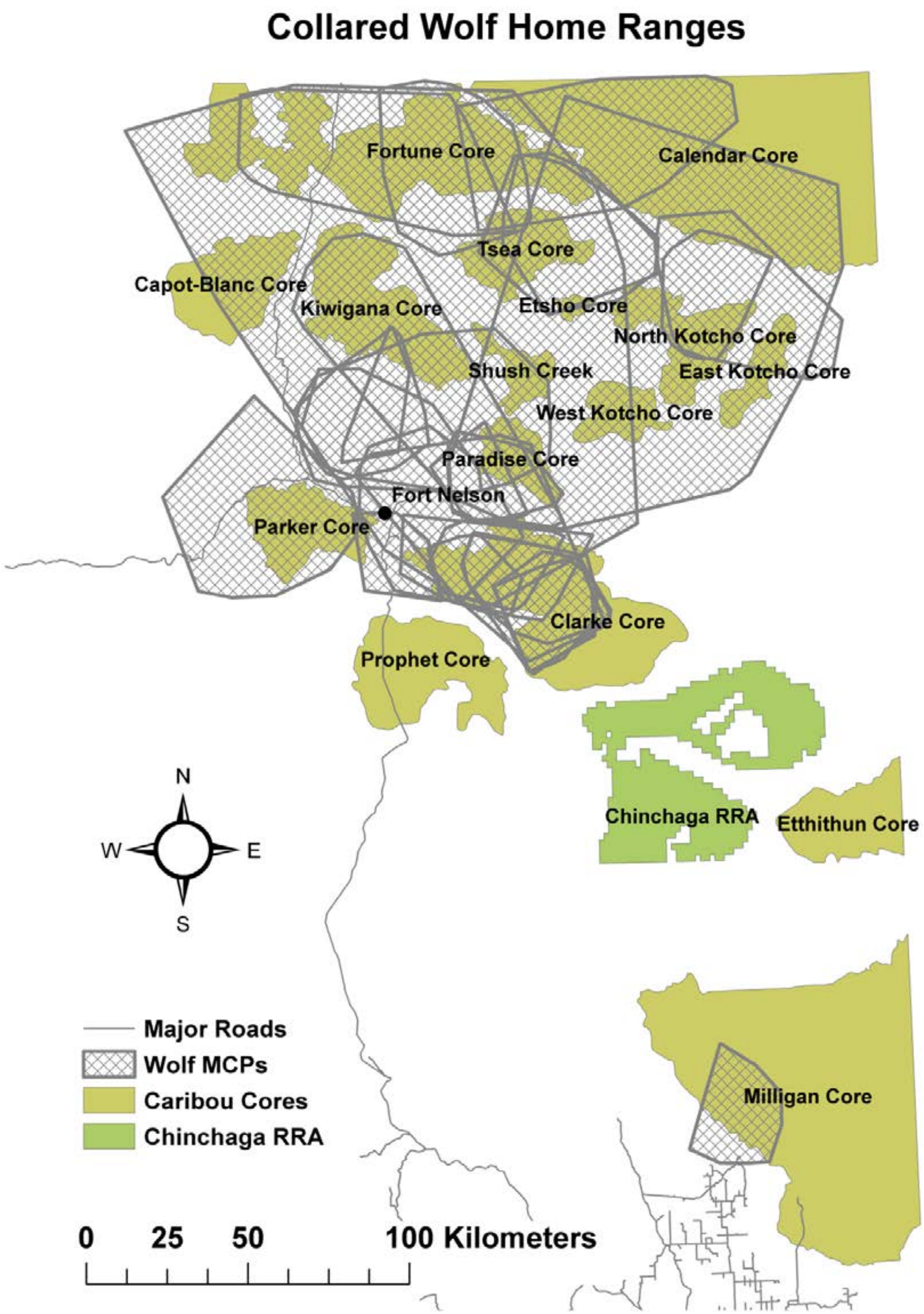

Figure 14. Annual home ranges (100% Minimum Convex Polygons) of GPS-collared wolves in our study area. Although we have good coverage from the Clarke Core north, we currently have access to few data farther south.

Data Layers and Attributes

We have attributed many of the same landscape attributes to wolves and caribou as we are using in the moose resource selection modelling. We have maintained our 8 vegetation classes across all 3 species. Similarly, we believe that both distance to edge, length (m) of edge, and vegetation class diversity may influence wolf and caribou distributions; however, we calculated length of edge at different scales (500 m for moose and 100 m for wolves) based upon mean hourly movement rates. Elevation, slope, and terrain roughness were additional shared landscape attributes, and given project objectives, we were also interested in anthropogenic disturbances, such as distance to seismic and roads and length of seismic and roads at 500 m and 100 m for wolves and caribou, respectively. To date, we have not included fire or cutblock layers for wolf locations, because we believe these layers may attract moose and a moose layer will be included as a covariate in our wolf resource selection modelling. Fire and cutblocks have been included as a caribou attribute, but we did not impose the 30 year cutoff seen in moose and instead modelled burned versus areas with no records of burns and harvested versus areas with no record of harvest. This approach was meant to reflect the slow recovery of boreal caribou landscapes following disturbance.

Analyses of Encounters and Risk

Beyond our wolf resource selection model, we plan on modelling risk to caribou in 2 ways. First, we are interested in identifying the factors that increase the probability of an encounter between wolves and caribou, and second, we want to determine the drivers that result in a caribou mortality following an encounter. We used locations from 28 collared wolves and 104 collared caribou to identify nonlethal wolf-caribou encounters as defined by a wolf location being within 1971 m (mean 24-h caribou movement distance) of a caribou location within a 24-h period (Figure 15). We are using logistic regression to compare caribou locations to wolf-caribou encounters in order to predict landscape attributes that increase the probability of an encounter. Attributes tested will mirror the suite of covariates already attributed to caribou locations. To model the probability of being killed following an encounter, we are using logistic regression to compare wolf-caribou encounters to caribou mortality locations assigned to

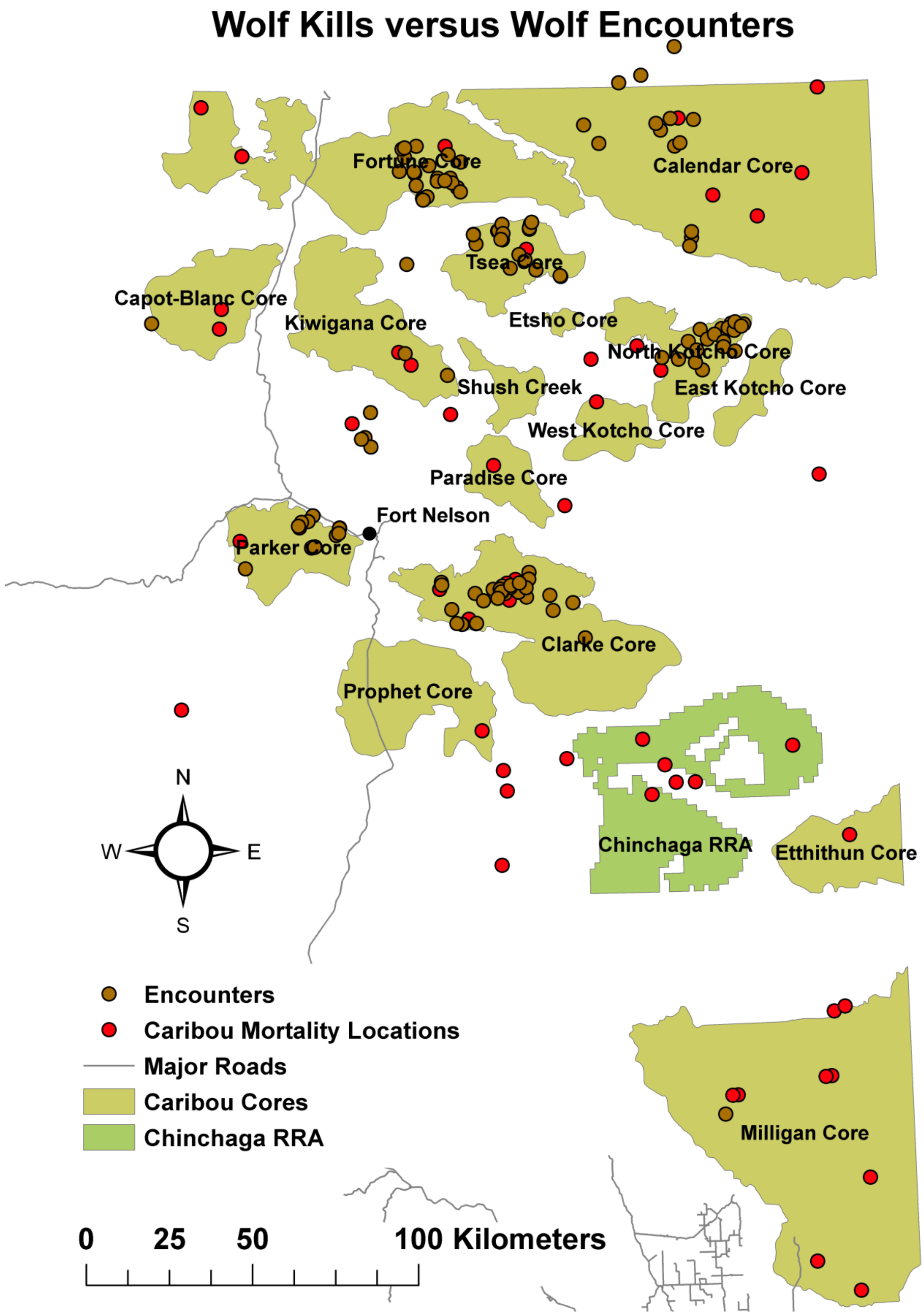

Figure 15. Locations of encounters (based on proximity of radio-collared wolves and caribou; see text) within the study area.

wolves (Figure 15). These models will include a limited version of landscape attributes thought to alter the vulnerability of caribou to predation, such as vegetation classes, vegetation diversity, length of edge, slope, standard deviation of slope, and distance to and length of seismic and roads. Preliminary analyses indicate that locations near seismic are more prone to encounters, but do not pose an increased risk of mortality following an encounter, likely because the bulk of caribou locations occur farther from seismic areas. We have also found that areas with large amounts of bog reduce the risk associated with encounters. Once the top models for all 3 risk layers are established, we plan on testing risk layers against used and available caribou locations to determine which layer best predicts caribou selection.

Activity 5: Conduct caribou survival analysis using all data

Ultimately, our work is attempting to identify the drivers of caribou survival in the boreal with a particular interest in the direct and indirect effects of manageable anthropogenic activities. Specifically, we are interested in how natural gas development may alter risk via increased wolf search efficiency or apparent competition via changes in moose and wolf distribution or abundance, and how those interactions can be managed to reduce risk to caribou. In the coming year, we plan to utilize our moose resource selection and wolf risk models as covariates in modelling caribou survival. Those analyses will also include other landscape attributes, in order to examine these complex processes and interactions.

Our current plan is to run 2 separate survival analyses, which together will allow us to fully utilize the available data. Because of the way that the Research and Effectiveness Monitoring Board (REMB) caribou-monitoring program developed, caribou survival data fall into different categories of data collection. Initially, caribou were affixed with VHF collars, which required monthly (or sometimes less frequent) monitoring flights to ascertain the position of the collared animal and whether that animal was alive or dead. More recently, the collaring program transitioned to using GPS satellite collars (Table 5), which provide continuous information about location and remote notifications of mortalities. Including the VHF collars greatly expands our sample size, but prevents us from capitalizing on the fine-scale location

Table 5. Number of GPS and VHS collared caribou and the number of caribou mortalities for each core. Location data is not available for all GPS collars.

Core	Collar	Collared	Mortalities
Calendar	GPS	15	4
	VHF	18	7
Capot-Blanc	GPS	7	1
	VHF	8	4
Chinchaga RRA	GPS	21	7
	VHF	6	2
Clarke	GPS	11	0
	VHF	16	4
Etthithun	GPS	2	0
	VHF	1	1
Fort Nelson	GPS	9	3
	VHF	1	1
Fortune	GPS	18	4
	VHF	12	3
Kiwigana	GPS	14	2
	VHF	15	9
Kotcho	GPS	14	3
	VHF	17	6
Milligan	GPS	21	4
	VHF	19	7
Paradise	GPS	1	1
	VHF	6	3
Parker	GPS	11	0
	VHF	9	5
Prophet	GPS	12	4
	VHF	2	1
Tsea	GPS	6	0
	VHF	8	2
Outside Core	GPS	2	2
	VHF	5	2
Total	GPS	164	35
	VHF	143	57

data provided by GPS collars. Therefore, we are first planning on conducting a high-level analysis utilizing all collars (VHF and GPS) that will examine the relationship between core attributes and the survival of individuals within each core. As a first step, we have begun evaluating the available data and fate of collared individuals across cores since the inception of the study (Table 5). We believe this analysis will enable us to evaluate the influence of moose, predation, and disturbance on caribou survival in a straightforward manner. Subsequently, we will conduct a second, fine-scale analysis using only GPS collars and Cox-proportional hazard models (sensu DeCesare et al. 2014) to address more detailed information about factors that contributed to mortalities of GPS-collared animals. We think this approach will illuminate the mechanisms contributing to declines in caribou abundance and provide reliable information for future management decisions moving forward.

Extension Plan and Activities

Throughout the first year of this work, we have liaised regularly with Megan Watters (FLNRO) in terms of mortality investigations and other project related issues – both via conference calls and during face-to-face meetings at UNBC. These meetings included project-specific consultations with Megan, Steve Wilson (REMB Board), Kathy Parker (UNBC), and Chris Johnson (UNBC) and sessions regarding the direction of REMB-funded research, along with the strategic planning research activities. Additionally, we have provided support roles by providing data and consultation to guide moose distance surveys completed by FLNRO staff and contractors in Region 7B (Peace) and Matt Mumma has participated with FLNRO on several RFP review teams related to contracts for moose data collection.

The extension plan for year 1 activities included: a presentation to the REMB-summarizing the approach used in the research, the findings, and the implications; and a “presentation to the BC OGRIS Fund and Invited Guests”-summarizing Year 1 activities. Because much of the work in year 1 was targeted at organizing and screening data, these activities are being rolled over into year 2 of the project and will take the form of one or more REMB webinars. Other planned extension activities consist of at least two conference presentations for 2016–2017, including a presentation at 16th North American Caribou Workshop (Title: Understanding the impact of linear features on predation risk and avoidance of wolves by boreal caribou (accepted); Authors: Mumma M., Gillingham M., Johnson C., Parker K., and M. Watters) and an anticipated presentation at the 50th Moose Conference and Workshop (Tentative Title: Understanding the drivers of moose distribution and density in the boreal).

Plans for Next Reporting Period

Work will continue on all activities:

A1) receive and analyze moose telemetry data;

A2) develop initial moose use/selection layers (existing data);

A3) develop initial caribou risk layers using existing data;

A4) refine caribou risk layers using incoming moose, caribou, and wolf data; and

A5) conduct caribou survival analysis using all moose, caribou, and wolf data.

with emphasis on activities 4 and 5.

Recommendations

Based on our work to date, we offer the following recommendations targeted primarily at the upcoming collaring effort:

- Throughout the balance of the project, all recovered collars (dropped off, mortalities, recollaring, etc.) should be directly download (whether from moose, caribou or wolves) before those collars are either redeployed or sent in for any refurbishment.

- If opportunities arrive, additional wolves should be collared in the southern half (Chinchaga RRA, Etthithun Core, and Milligan Core) of the boreal study area.

- Monitoring and timely assessment of moose and caribou mortality locations should continue to provide accurate cause of death assessments.

Acknowledgements

Support for this work is being provided by the BC Oil and Gas Research and Innovation Society (BC OGRIS) and the Research and Effectiveness Monitoring Board (REMB). Collar deployment and field monitoring of moose were initiated and overseen by the BC Ministry of Forests Lands and Natural Resources in conjunction with Diversified Environmental Services (collaring), Ingebjorg Jean Mattson (mortality site investigation), and Caslys Consulting (collar monitoring). Indirect support was provided by the University of Northern British Columbia. We would also like to thank Ducks Unlimited Canada for allowing us to access their detailed habitat classification data.

Literature Cited

DeCesare, N.J., M. Hebblewhite, M. Bradley, D. Hervieux, L. Neufeld, and M. Musiani. 2014. Linking habitat selection and predation risk to spatial variation in survival. Journal of Animal Ecology 83:343–352.

DeCesare, N. J., M. Hebblewhite, H. S. Robinson, and M. Musiani. 2010. Endangered apparently: the role of apparent competition in endangered species conservation. Animal Conservation 13:353–362.

Demars, C. A. 2015. Calving behavior of boreal caribou in a multi-predator, multi-use landscape. PhD. Dissertation. University of Alberta, Edmonton.

Ducks Unlimited Canada. 2013. BC boreal plains enhanced wetlands classification user's Guide. 58 pp. Ducks Unlimited Canada, Edmonton, Alberta. Prepared for: Ducks Unlimited Canada; Imperial Oil Resources; Encana; Devon Energy Corporation; The PEW Charitable Trusts; and the U.S. Forest Service; U.S. Fish and Wildlife Service through the North American Wetlands Conservation Act (NAWCA).

Environment Canada. 2012. Recovery Strategy for the Woodland Caribou (*Rangifer tarandus caribou*), Boreal population, in Canada. Species at Risk Act Recovery Strategy Series. Environment Canada, Ottawa.

Gillingham, M. P., and K. L. Parker. 2008. Differential habitat selection by moose and elk in the Beas-Prophet Area of Northern British Columbia. Alces 44: 41–63.

Grohmann, C. H., M. J. Smith, and C. Riccomini. 2011. Multiscale analysis of topographic surface roughness in the Midland Valley, Scotland. IEEE Transactions on geoscience and Remote Sensing 49: 2000–2013.

Gustine, D. D., Parker, K. L., Lay, R. J., Gillingham, M. P., and D. C. Heard. 2006. Calf survival of woodland caribou in a multi-prey ecosystem. Wildlife Monographs 165: 1–32.

Hebblewhite, M., Merril, E. H., and T.L. McDonald. 2005. Spatial decomposition of predation risk using resource selection functions: an example in a wolf–elk predator–prey system. Oikos 111: 101–111.

Johnson, C. J. and D. E. Russell. 2014. Long-term distribution responses of a migratory caribou herd to human disturbance. Biological Conservation 177: 52–63.

Latham, A. D., M. C. Latham, K. H. Knopff, M. Hebblewhite, M., and S. Boutin. 2013. Wolves, white-tailed deer, and beaver; implications of seasonal prey switching for woodland caribou declines. Ecography 36: 1276–1290.

McLellan, B. N., R. Serrouya, H. U. Wittmer, and S. Boutin. 2010. Predator-mediated Allee effects in multi-prey systems. Ecology 91:286–292.

McNay, S., D. Webster, and G. Sutherland. 2013. Aerial moose survey in north east BC 2013. Report to SCEK and the BC boreal caribou implementation plan. Available at http://scek.ca/sites/default/files/bcip-2013-02-moose-survey-core-caribou-areas-march-2013.pdf (accessed June 2014).

R Development Core Team. 2011. R: A Language and Environment for Statistical Computing. Vienna, Austria : the R Foundation for Statistical Computing. ISBN: 3-900051-07-0. Available online at http://www.R-project.org/.

Shannon, C. E. and W. Weaver. (1963) The mathematical theory of communication. University of Illinois Press, Urbana, Illinois, USA.

Thiesen, C. 2010. Horn river Basin Moose Inventory – January/February 2010. Peace Region Technical Report. Ministry of Environment, Fort. St. John, BC.