# Seeking Sanctuary – the Neonatal Calving Period among Central Mountain Caribou (Rangifer tarandus caribou)

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*(Rangifer tarandus caribou)*

Authors

B.R. Nobert, Caribou Program, fRI Research, 1176 Switzer Drive, Hinton, Alberta T7V 1V3, Canada (bnobert@friresearch.ca)

S. Milligan, Caribou and Grizzly Bear Programs, fRI Research, 1176 Switzer Drive, Hinton, Alberta T7V 1V3, Canada (smilligan@friresearch.ca)

G.B. Stenhouse, Grizzly Bear Program, fRI Research, 1176 Switzer Drive, Hinton, Alberta T7V 1V3, Canada (gstenhouse@friresearch.ca)

L. Finnegan, Caribou Program, fRI, 1176 Switzer Drive, Hinton, Alberta T7V 1V3, Canada (lfinnegan@friresearch.ca)

Corresponding Author

Barry R. Nobert

1176 Switzer Drive

Hinton, Alberta, Canada T7V 1V3

(780) 536 – 0515

bnobert@friresearch.ca
Title

Seeking Sanctuary – the Neonatal Calving Period among Central Mountain Caribou (*Rangifer tarandus caribou*)

Authors

B.R. Nobert, S. Milligan, G.B. Stenhouse & L. Finnegan

Abstract

Woodland caribou (*Rangifer tarandus caribou* (Gmelin, 1788)) populations have declined throughout their range. With the goal of better understanding habitat selection and fidelity during the neonatal calving period (0 – 4 weeks), we applied a non-invasive method that estimates calving events and subsequent survival based on changes in movement rates among GPS-collared female caribou. We examined a long-term GPS-collar dataset (1998 – 2014) collected from 81 adult female caribou in two central mountain herds in Alberta and British Columbia, Canada. Although we were unable to validate our results with aerial surveys and pregnancy tests, our estimates of parturition rates, survival rates, calving dates and habitat selection were consistent with previous studies. We identified 83 calving sites. Female caribou selected calving sites and post-parturition habitat on high elevation ridge-tops with gradual slopes and avoided anthropogenic linear features. Female caribou displayed low fidelity to inter-annual calving ranges with an average distance of 8.7 km between calving ranges. Fidelity was lower in areas with high seismic line density. Conservation of high elevation habitat with limited anthropogenic disturbance is likely to provide the greatest benefit to central mountain caribou during the neonatal calving period, and represents a potential management strategy for population recovery efforts.
Keywords

woodland caribou, *Rangifer tarandus caribou*, calving, habitat, central mountain caribou
Introduction

Central mountain woodland caribou have been recommended for endangered status in Canada (COSEWIC 2014). Persistence of caribou in Alberta is especially uncertain because populations have been declining over the last century (ASRD and ACA 2010) with decreasing population sizes reported in 10 of 14 herds monitored (Hervieux et al. 2013; Environment Canada 2014). Habitat degradation and altered predator-prey dynamics are thought to be the major contributors to declines in caribou distribution and abundance (Festa-Bianchet et al. 2011; Hervieux et al. 2013). Oil and gas exploration and timber harvesting is believed to have reduced caribou habitat (Johnson et al. 2015), and increased alternative prey species within caribou ranges (Messier 1994; Latham 2009; Bowman et al. 2010). This in turn has resulted in apparent competition by increasing predator densities within caribou ranges and overall predation risk for caribou (Brown et al. 2007; Vors et al. 2007; DeCesare et al. 2010).

Calf survival is an important component of caribou population growth (Gaillard et al. 2000), and low recruitment is a problem for several caribou populations in Alberta (Hervieux et al. 2013). Predation is the main natural cause of calf mortality (Linnell et al. 1995; Gustine et al. 2006). Research suggests calf predation is probably most important for population growth during the calf’s first winter (6 – 12 months) prior to recruitment into the population as a yearling (Hebblewhite et al. 2007a; Johnson et al. 2010; DeCesare et al. 2012). However the neonatal period is an especially vulnerable time for predation (Adams et al. 1995; Gustine et al. 2006) and there is limited information available on the neonatal period of a calves’ life (0 – 4 weeks of age) including parturition rates, neonatal calf survival, adult female habitat selection and calving range fidelity (Rettie and Messier 1998; Wittmer et al. 2005a; Pinard et al. 2012). The lack of research during this time period is in-part because neonatal calf mortality is believed to be
compensatory (Vaupel et al. 1979; Tveraa et al. 2003; Griffin et al. 2011), but primarily because it is logistically difficult as well as invasive to capture and observe caribou and calves using conventional means during this time such as aerial surveys (Whiting et al. 2012), blood samples from captured animals (Wood et al. 1986) and vaginal implant transmitters (Barbknecht et al. 2009).

An individual-based method (IBM) developed by DeMars et al. (2013) utilizes changes in movement rates of collared adult female caribou to estimate calving events and subsequent neonate calf survival, and so provides an opportunity to increase understanding of the central mountain caribou neonate period through a non-invasive approach. This approach was developed in North-Eastern British Columbia within four boreal woodland caribou herds (Designatable Unit (DU) 6; COSEWIC 2011) and external validation of results using a combination of aerial surveys and progesterone levels revealed this approach was highly accurate at detecting calving (>97% accuracy) and neonatal survival (87% accuracy, DeMars et al. 2013). For this study, our objective was to apply this non-invasive approach within herds in the central mountain caribou DU (DU 8, COSEWIC 2011) to determine if fecundity and neonatal survival may be contributing to declines in endangered central mountain caribou, and to identify important habitat for caribou during the calving season.

We applied the IBM from DeMars et al. (2013) to a long term GPS-collar data set (1998-2014) collected from 81 adult female caribou (hereafter caribou) from two central mountain caribou herds (Narraway and Redrock-Prairie Creek), in Western Alberta and Eastern British Columbia. Our specific objectives were to i) estimate calving events and neonate survival to four weeks of age, and ii) model habitat selection and calving range fidelity as a function of landscape, topography, and anthropogenic disturbance covariates. Because our study used a
historical data set, and because of the current endangered status of these herds (COSEWIC 2002; Hervieux et al. 2013; COSEWIC 2014), we could not directly validate estimated calving events or neonatal survival with observations. Instead, we evaluated IBM results by comparing our results to previous research that assessed calving rates, neonatal mortality rates, parturition dates and habitat selection within the same herds (Edmonds and Bloomfield 1984; Edmonds 1988) and in the same subspecies (Gustine et al. 2006; Gustine and Parker 2008; Pinard et al. 2012; DeMars et al. 2013), as well as porcupine caribou (*Rangifer tarandus granti* (Allen, 1902)) in Alaska (Adams et al. 1995; Barten et al. 2001; Jenkins and Barten 2005).

We predicted that the peak and range in calving dates would be consistent with calf aerial surveys within our study area (Edmonds 1988). We also predicted that calving dates would be similar to those observed in an adjacent region (Gustine et al. 2006), because among large herbivores the seasonal timing and synchrony of parturition typically coincides with the seasonal peak in food availability (Kerby and Post 2013) which should be similar within neighbouring regions. At a broad scale we predicted that estimated calving and neonatal survival rates would differ when compared to caribou in other regions because of local differences in plant phenology (Stoner et al. 2016), climatic conditions (Griffin et al. 2011), predator regimes (Linnell et al. 1995), hunter-harvest (Brown 2011) and population density (Wang et al. 2009), but we wanted to determine whether our estimated rates of calving and neonatal survival fell within the range reported across caribou herds in five other regions (Adams et al. 1995; Jenkins and Barten 2005; Gustine et al. 2006; Pinard et al. 2012; DeMars et al. 2013). We did not compare our estimated calving rates to pregnancy rates which are widely reported (Bergerud 1980; Gustine et al. 2007; Pachkowski et al. 2013) because they have the potential to over-estimate calving rates (Pinard et
al. 2012) as some caribou can undergo embryonic mortality during pregnancy (Russell et al. 1998).

During the calving season, caribou have demonstrated a tendency to give birth in one location, then over-time move away from the calving site to reduce predation risk (Gustine et al. 2006). Because of this behaviour we considered habitat selection during the calving season as a two-stage process 1) calving site selection, and 2) caribou habitat selection during the post-parturition period (when the calf is 0 – 4 weeks of age). For habitat selection models, we predicted that females would select areas at higher elevation and on steeper slopes to isolate themselves from predators (Bergerud and Page 1987; Barten et al. 2001) like wolves (*Canis lupus* (L., 1758)) that prefer lower elevations, and more gradual slopes (Gustine et al. 2006; Whittington et al. 2011). We also predicted that caribou would select areas with lower densities of anthropogenic disturbance (Skarin et al. 2008; Vistnes and Nellemann 2008; Pinard et al. 2012) because of the potential for greater predator encounters in those areas (Nielsen et al. 2004; Whittington et al. 2011) and because caribou generally avoid anthropogenic disturbances (DeCesare et al. 2010; Latham et al. 2013).

Finally, we considered calving range fidelity among caribou that had calves in two consecutive years, and predicted that fidelity to calving ranges would decrease with an increase in anthropogenic disturbance (Mahoney and Schaefer 2002; Faille et al. 2010) and snow accumulation (Popp et al. 2011). Range fidelity has implications for conservation strategies, with high fidelity increasing the success of conservation areas in current high use areas but low fidelity requiring the conservation of larger tracts of land to account for potential future shifts in distribution (Faille et al. 2010). The results of this study will contribute to an increased understanding of the early calving period among central mountain caribou, including identifying
areas important for conservation, and thus help to inform conservation strategies and land-use plans.

Methods and materials

STUDY AREA

Our study area included the range of the Narraway and Redrock-Prairie Creek caribou herds in Western Alberta and Eastern British Columbia, Canada (Fig. 1). The ranges of these herds encompass foothills, subalpine, and alpine natural subregions (Natural Regions Committee 2006). Upland areas of the foothills are characterized by lodgepole pine (*Pinus contorta* (Douglas)) and white spruce (*Picea glauca* ((Moench) Voss)) forests with patches of trembling aspen (*Populus tremuloides* (Michx.)). Lowland areas in the foothills are dominated by black spruce (*Picea mariana* (P. Mill)) and tamarack (*Larix laricina* ((Du Roi) K. Koch)). The subalpine subregion is dominated by Engelmann spruce (*Picea engelmannii* (Parry ex Engelm.)) and subalpine fir (*Abies lasiocarpa* ((Hooker) Nuttall)), whereas graminoids and sedges (*Carex spp.*) are characteristic of the alpine subregion. Overall, the study area has a continental climate with long cold winters and short cool summers.

The habitat diversity within the study area supports a variety of other species including bighorn sheep (*Ovis canadensis* (Shaw, 1804)), mountain goats (*Oreamnos americanus* (Blainville, 1816)), elk (*Cervus elaphus* (L., 1758)), moose (*Alces alces* (Gray, 1821)), white-tailed deer (*Odocoileus virginianus* (Zimmermann, 1780)) and mule deer (*O. hemionus* (Rafinesque, 1817)). Wolves, grizzly bears (*Ursus arctos* (L., 1758)) and cougars (*Felis concolor* (L., 1771)) also occur in the study area and are the main predators of caribou (Wittmer et al. 2007). Other predators include black bears (*U. americanus* (Pallus, 1780)), lynx (*Lynx*
canadensis (Kerr, 1792)), wolverines (Gulo gulo (L., 1758)) and coyotes (C. latrans (Say, 1823)).

Land use activities within the study area include mining, forestry, oil and gas exploration and outdoor recreation (e.g., All Terrain Vehicles, hiking, camping). The intensity of these activities varies across the study area. The Narraway range contains a small portion of the Kakwa Wildland Provincial Park in Alberta, and portions of five different protected areas in British Columbia, amounting to 19% of its total range (Fig. 1). The Redrock-Prairie Creek range contains a large portion of the Kakwa Provincial Park in British Columbia, and portions of three different protected areas in Alberta, amounting to 42% of its total range.

GPS-COLLAR DATA

We used GPS location data collected from adult female caribou collared within the Narraway and Redrock-Prairie Creek herds between 1998 and 2014. These data were collected as part of a long-term caribou collaring program coordinated by Alberta Environment and Parks in collaboration with Weyerhaeuser Co. Ltd. Caribou were captured using helicopter net-gunning and fitted with GPS-collars (Lotek GPS 1000, 2000, 2200, 3300 and 4400 models; Lotek, Newmarket, Ontario, Canada) as outlined by Slater (2013). Because the collaring effort spanned multiple years the GPS-collar type and tracking schedule varied across the study period (i.e., 1, 2, 3, 4 and 6 hour fix intervals). All capture protocols were approved by the University of Alberta Animal Care Committee (Protocol 731910) and the Government of Alberta (Protocol 008). We limited our analysis to GPS locations taken from 1 May to 14 July, which encompasses the expected calving season from mid-May to mid-June typical among caribou (Kelsall 1968; Bergerud 1974; Fuller and Keith 1981). We removed all locations with a dilution of precision
(DOP) greater than 12 because these locations are associated with a poor measurement of positional precision (MELP 2001). The GPS-collars had an average fix rate success of 88%; to account for potential bias in habitat selection induced by missing fixes (Frair et al. 2004) we weighted used GPS locations by the inverse probability of obtaining a successful fix based on models developed by (Hebblewhite et al. 2007b). Our final dataset consisted of 81 female caribou (39 Narraway, 42 Redrock-Prairie Creek). Efforts were made to deploy collars on adult caribou based on body size and tooth eruption however exact ages were not determined meaning some collars may have been deployed on non-reproductive females (<3 years old). Because some individuals (42%) were collared for multiple years we had 117 total observations (60 Narraway, 57 Redrock-Prairie Creek), which we termed caribou-calving-seasons.

IBM – PREDICTING CALVING EVENTS AND NEONATAL CALF SURVIVAL

We used the IBM of DeMars et al. (2013) to estimate the timing and location of calving events and subsequent calf survival from the GPS-collar dataset of caribou. The IBM is a modelling approach that analyzes movement rates – specifically mean step lengths – for sudden and marked reduction (i.e., a break point) from normal movement patterns. It is based on three \textit{a-priori} movement models representing the three states of females during the calving season: i) did not calve (M$_0$); ii) calved and calf survived to 4 weeks (M$_1$); and iii) calved with subsequent calf loss prior to 4 weeks (M$_2$). Step lengths in M$_0$, M$_1$, and M$_2$ are assumed to be exponentially distributed, therefore the scale parameter of that distribution (interpreted as the step length) differs for each model. For caribou that do not calve (M$_0$), the scale parameter (b$_0$) of M$_0$ remains constant over time. In contrast, for females that do calve (M$_1$, M$_2$), the scale parameter (b$_1$) drops abruptly during parturition from its pre-calving constant, creating an initial break point (BP$_1$). When a calf survives (M$_1$) the scale parameter linearly increases until the calf achieves an adult
movement rate. However, if the calf is lost \( M_2 \) there is an abrupt shift back to the pre-calving movement rate creating a second break point \( B_{P_2} \). IBM model parameters are estimated using an approximation of the maximum likelihood estimation (see Supplementary Material of DeMars et al. 2013) and are evaluated using Akaike’s Information Criterion (AIC, Burnham and Anderson 2002). The initial break point \( B_{P_1} \) is then linked to a particular GPS record and is used to identify the timing and location of the calving site for caribou predicted to have calved. While the second break point \( B_{P_2} \) is associated with the timing and location of calf mortality.

This IBM was developed using GPS-collar data from 24 adult caribou observed during the 2011 calving season (DeMars et al. 2013). In brief, DeMars et al. (2013) validated model results using blood serum progesterone-based pregnancy status determined during collaring (January – March) combined with weekly aerial surveys during the calving season to confirm calving events. Every female identified as pregnant during capture was later observed with a calf. To assess neonate survival 12 caribou were surveyed until their calf reached four weeks of age, and every observation of a lost calf was confirmed with an additional survey. Additional data from 2012 \( (n = 15, 3 \) unique caribou not included in the 2011 data) and 2004 \( (n = 10, \) all unique from 2011) were used to test the method predictions (DeMars et al. 2013). Based on this field validation DeMars et al. (2013) found that the IBM correctly predicted parturition events for 39 of 40 \( (97.5\%) \) caribou that were pregnant or observed with a calf. Survival to four weeks of age was correctly predicted 78\% of the time across all years, but when 2004 data were withheld accuracy improved to 87\%. The authors speculated that the lower accuracy in 2004 was attributed to the lower mean fix rate success \( (77\%) \) during that year when compared to 2011 \( (95\%) \) and 2012 \( (96\%, \) DeMars et al. 2013).
Prior to our application of the IBM analysis, we organized GPS locations into a time-series using the adehabitatLT package (Calenge 2006) in R version 2.13 (R Development Core Team 2014). As GPS locations are rarely recorded at exact times we allowed a deviation one tenth of the time interval (i.e., 24 minutes for 4 hour fix interval). We assigned missing GPS fixes a “NA” value, removed the top 1% of step lengths from the time series and calculated step lengths from successive GPS locations. For estimating calving events and subsequent survival we used GPS-collar data with an average of 88% fix success rate during the period of interest, which corresponds to ~80% accuracy of “detecting” calving events and survival based on a post-hoc analysis of the effects of data quality by DeMars et al. (2013).

*Sensitivity Analysis* - Because our location dataset contained a variety of fix rates (1 - 6 hours), and the DeMars et al. (2013) method was developed using caribou collars with a 4 hour interval between GPS-collar fixes, we evaluated the consistency of “detecting” a calving event and subsequent neonatal calf survival when the fix interval was shorter (2 hours) or longer (8, 12, 16, 20 and 24 hours) than 4 hours. Because the actual calving status of collared caribou was unknown, we considered the IBM results at the 4 hour to be the standard against which all results would be compared. We calculated specificity, sensitivity and overall accuracy relative to a standard using the caret package in R (Kuhn 2014). To determine if the predictions differed when compared to the 4 hour standard we used a McNemar’s Chi-squared test (Kuhn 2014; R Development Core Team 2014). We repeated this analysis with the 2 hour fix rate as the standard to check the consistency of the results.

CALVING RANGE FIDELITY
For those caribou that had a calf in consecutive years, we calculated calving site fidelity as the mean distance among all possible pairs of GPS-collar locations during the post-parturition period in each year. The post-parturition period started at the date of parturition and continued until either the calf was lost, or in the case of a calf surviving, until four weeks after the parturition date.

We modeled fidelity as a function of herd (Narraway and Redrock-Prairie Creek), apparent neonatal calf survival, snow depth and disturbance using linear models. We ranked competing linear models using AIC corrected for small sample size ($\text{AIC}_C$; Burnham and Anderson 2002). Herd was a binary covariate indicating either Narraway (1) or Redrock-Prairie Creek (0). Apparent neonatal calf survival in the first of the two consecutive years was based on the IBM results ($M_1$ vs $M_2$). The expectation was for a caribou to display greater calf site fidelity when the calf in the first year survives to four weeks of age (Rettie and Messier 2001; Faille et al. 2010). We considered spring snow depth in the first and second year hypothesizing that greater snow depth in either year could hamper the ability of a caribou to occupy its calving site. Snow depth was measured as the average snow depth during the month of April in Grande Prairie, Alberta, obtained from historical Environment Canada weather data (http://climate.weather.gc.ca/). The city of Grande Prairie is located approximately 140 km NE of centers of both the Narraway and Redrock-Prairie Creek ranges and is the nearest weather station to our study area with continuous weather data from 1998–2014. Finer scale snow data, which would account for snow accumulations in microhabitats, were not available.

We measured disturbance as the proportion of burns, cutblocks and well sites; and the density of seismic lines and roads within a 5-km circular buffer averaged across all GPS-collar locations during the post-parturition period. For each disturbance type we considered two
alternative covariates: i) average disturbance across all GPS locations in the first year and ii) average disturbance across all GPS locations in the second year. To account for females potentially moving away from their parturition site after calving (Gustine et al. 2006), in particular those that had calves surviving to four weeks of age, we repeated the analysis using only locations from the first day post-parturition.

HABITAT SELECTION

To examine calving site selection and post-parturition habitat selection, we constructed resource selection functions (RSF) based on a used-available design (Manly et al. 2002). Because habitat selection among caribou is scale dependant (Mayor et al. 2009; DeCesare et al. 2012), we examined patterns of selection at two spatial scales: i) large scale selection relative to habitat available throughout the entire herd range (herd-range) and ii) finer scale selection relative to an individual spring calving season home-range (home-range; Johnson et al. 2006). The used-available design for each analyses are described below, followed by the model building process.

Calving Site Selection – We considered the GPS-collar location associated with the first break point in movement rate (BP$_1$) identified with the IBM as the used calving site, and we paired each individual calving site with 20 available locations. At the herd-range scale, we randomly drew available points from within a minimum convex polygon created from pooled GPS-collar locations by herd obtained throughout the year between 1998 and 2014. At the home-range scale, we drew available points from within each caribou-calving-season 95% kernel density home-range calculated using the Gitzen plug-in method (Gitzen et al. 2006) in Geospatial Modeling Environment (GME, Beyer 2012). We constructed caribou-calving-season home-ranges using GPS-collar locations spanning from the start of the spring migratory period until the date of
parturition. We considered 5 May and 10 May as the start of spring migration for the Narraway
and Redrock-Prairie Creek herds, respectively, based on a concurrent study by MacNearney et al.
(2016), where seasons for these herds were defined using an individual-based recursive
partitioning method that identifies transition dates between seasons based on inflection points in
daily movement rates (Rudolph and Drapeau 2012). We pooled all location data from both herds
to increase the sample size for the calving site selection analysis.

Post-Parturition Habitat Selection - To quantify habitat selection of caribou post-parturition, we
examined GPS-collar locations of caribou recorded between the parturition date and four weeks
post-parturition. For caribou that lost calves (i.e. IBM M2 was the most supported), we only
considered GPS-collar locations between the parturition date and the apparent mortality date of
the calf identified using the IBM.

At the herd-range scale, we considered the used locations to be 200 random locations
sampled within a 95% kernel density home-range for each caribou-calving-season (Gitzen et al.
2006). These used locations were compared to a set of 1000 random available locations within a
minimum convex polygon encompassing the GPS-collar locations for each herd throughout the
year between 1998 and 2014. At the home-range scale, we compared each used GPS location to
5 random available locations within each caribou-calving-season 95% kernel density home-
range. Only GPS locations within the 95% home-range were considered for this analysis.

Model Building - For both analyses we built models using the logistic form of a Bayesian
generalized linear model in the “arm” package in R (Gelman and Su 2014). This approach
allowed models to be fit despite complete linear separation in logistic regression (Gelman et al.
2008), an issue which arose in our analysis because human disturbance was not common at higher elevations where calving occurred.

Within potential models we considered landscape factors previously shown to influence caribou habitat selection (Johnson et al. 2004; Apps and McLellan 2006; DeCesare et al. 2012). We describe these covariates in detail in Appendix A. We did not include landscape covariates in the same model if they were strongly correlated ($|r| > 0.60$). We carried out model selection with a three step hierarchical process. First, within each of three factors (topography, aspect and cover) all combinations of covariates were considered as competing models. Second, we combined the resulting top models from each of the combinations of covariates into an initial “base model”. We compared the base model to nested models with one covariate removed. If removing a covariate improved the AIC score we eliminated that covariate from the model. This process continued until no covariate removal improved AIC scores. Third, we added disturbance covariates to the base model, post stepwise removal, and evaluated all alternative models using AIC.

For the post-parturition habitat selection analysis, to account for correlations in habitat selection within individual caribou, we adopted a two-stage modeling approach where we first built individual habitat selection models for each caribou-calving-season, and then we averaged these individual models to produce a population level model (Fieberg et al. 2010). We averaged individual coefficients ($\beta_i$) as an inverse weighted mean ($\hat{\beta}$, Murtaugh 2007) with weights ($w_i$) proportional to the reciprocal of individual squared standard errors:

$$\hat{\beta} = \Sigma_{i=1}^{N} w_i \beta_i$$

equation 1
\begin{align*}
    w_i &= \frac{1}{\sum_{j=1}^{N} 1/\left[\text{SE}(\beta_j)\right]^2} \quad \text{equation 2}
\end{align*}

And the standard error of the weighted average coefficient is calculated as:

\begin{align*}
    \text{SE}(\hat{\beta}) &= \sqrt{\frac{\sum_{i=1}^{N} w_i(\beta_i - \hat{\beta})^2}{N-1}} \quad \text{equation 3}
\end{align*}

where \( N \) is the total number of individuals. Using this approach we built four separate population averaged post-parturition habitat selection models, each a unique combination of herd (Narraway, Redrock-Prairie Creek) and scale (herd-range, home-range).

The model selection process for the post-parturition habitat selection analysis varied from the calving site selection analysis in two ways. First, because we built individual models we ranked competing models based on AIC weights and considered the highest average AIC weight across caribou-calving-seasons as the best model. In addition, at the home-range scale we built models by including disturbance covariates one at a time and then only averaged AIC weights among caribou-calving-seasons that were “exposed” to that disturbance type. We considered exposure to be at least one used and available location within 1 km of a cutblock, well site, seismic line, or road, and within at least 70 m for burns.

To evaluate the ability of the final models to predict habitat selection we applied a k-fold cross-validation design (Boyce et al. 2002). The method withholds a random subset of 20% of the individual caribou-calving-seasons within the model dataset. We used the remaining 80% to parameterize the model and predict the values for the withheld subset of data. For the withheld dataset, we divided predicted values into 10 ranked bins, recorded the frequency of used points within each of these ranked bins, and calculated the Spearman’s ranked correlation coefficient.
between the frequency of used points in each bin relative to the bin values. We repeated this process 99 times and report the average of the Spearman’s correlation across these 100 comparisons.

To map the relative probability of calving site selection and post-parturition habitat selection of habitat selection models we used the following exponential equation:

\[ h(x) = \exp(\beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_k x_k) \] equation 4

Where \( \beta_1 \ldots \beta_k \) are the non-intercept parameters from the logistic generalized linear model allowing for predicted model values (\( h \)) to reflect the relative probability of selection (Johnson et al. 2006; Lele et al. 2013).

LANDSCAPE VARIABLES

For the purpose of modeling habitat selection, we considered landscape features known to be important to caribou ecology, habitat selection and mortality risk. Central mountain caribou occur at higher elevations during the spring calving season (Edmonds and Bloomfield 1984; Edmonds 1988), and typically select for intermediate elevations and slopes (Johnson et al. 2004; DeCesare et al. 2012), and higher topography like ridges and upper slopes (Bergerud et al. 1984; Dussault et al. 2012). We used a 30 x 30 m resolution Digital Elevation Model to create a topographic position index (TPI), as well as to provide measures of slope, elevation and aspect. Topographic position index (TPI) is the difference in elevation between a central cell and the mean elevation within a surrounding window. Higher TPI values correspond to hill tops and ridges while low values indicate valley bottoms and canyons. We calculated TPI within a 1-km circular moving window using Landfacet Corridor Designer for ArcGIS (Jenness et al. 2013).
We chose a 1-km radius because within our study area DeCesare et al. (2012) found that TPI measured at this scale contributed to caribou habitat selection. We considered aspect of the terrain because of the potential for microclimatic effects induced by higher solar radiation in southern aspects influencing snow depths and duration (López-Moreno et al. 2013), as well as vegetation phenology (Hebblewhite et al. 2008). To ease interpretation of aspect measurements we quantified aspect as two indices: eastness and northness calculated as the sine and cosine of aspect in radians, respectively.

We obtained both snow cover and NDVI spatial imagery from Moderate Resolution Imaging Spectroradiometer (MODIS) data. We calculated snow cover as the percent of days a 500-m pixel was snow covered over a 28 day period beginning at the peak calving date. Vegetation productivity was mapped at a 250-m resolution based on Normalized Difference Vegetation Index (NDVI), an index of vegetation productivity from -1 to 1. Vegetation productivity could be an important influence on caribou habitat because of the need for quality forage to meet the energy requirements of lactation associated with calving (Crête and Huot 1993). In contrast, snow acts as both a physical impediment to movement (Antifeau 1987) and access to vegetation (Rominger and Oldemeyer 1990; Johnson et al. 2001), which increases energetic demands of caribou (Mosser et al. 2014) and may also increase visibility to predators (Bergerud and Page 1987; Adams et al. 1995).

Among anthropogenic disturbance we considered areas where timber harvest occurred (i.e., cutblocks) as well as roads, seismic lines and oil and gas well sites (see Appendix A). For natural disturbance we included burned habitat, which we determined from the perimeters of historical wildfires. We considered only burns which occurred less than 60 years prior based on research suggesting that caribou avoid burns of this age class (Joly et al. 2007, 2010). Disturbance
covariates were measured within a 5-km circular moving-window at the herd-range scale and 0.07-km at the home-range scale, because caribou within our study area have been shown to respond to disturbance at those scales (DeCesare et al. 2012). At the home-range scale we also considered disturbance covariates calculated as the distance to the nearest disturbance feature (km) based on an exponential decay function \(1 - \exp\left(-2 \times \text{distance (km)}\right)\). We chose the decay function to represent the diminishing effect of disturbance at large distances (e.g., > 2 km) compared to small ones (e.g., 0.1 km, Johnson and St-Laurent 2011; Johnson and Russell 2014).

Habitat selection among caribou varies with vegetation cover types like conifer forest, shrubs and water (Hins et al. 2009; DeCesare et al. 2012), with vegetation also influencing calf survival (Gustine et al. 2006). We utilized a 15 class vegetation cover classification map at a 30 x 30 m resolution for 2013 using Landsat-8 Operational Land Imager (OLI) spectral data and slope and elevation as ancillary datasets (Nijland et al. 2015). We merged the original 15 vegetation cover classes into eight cover classes: barren, herbaceous, wetland, regenerating, deciduous forest, mixed forest, open conifer forest and closed conifer forest (see Appendix A). We considered closed conifer as the reference category which also included all rare vegetation cover types (<1% of used or available locations). For calving site selection analysis, wetland was placed in the reference category because of its rarity, resulting in seven vegetation cover classes.
Results

IBM – PREDICTING CALVING EVENTS AND NEONATAL CALF SURVIVAL

Among 117 caribou-calving-seasons, we predicted 83 calving events (71% calved). In the Narraway herd 80% of monitored caribou calved ($n = 48$), which was higher ($p = 0.04, \chi^2 = 4.04, df = 1$, Pearson's Chi-squared Test) than in the Redrock-Prairie Creek herd where 61% of monitored caribou calved ($n = 35$). Calving dates for both herds peaked (50% of females calved) two days apart, 1 June for the Narraway herd and 30 May for the Redrock-Prairie Creek herd. The earliest calving date in the Narraway herd was 21 May and the earliest calving date in the Redrock-Prairie Creek herd was 18 May. The latest calving date was 19 June for the Narraway herd and 15 June for the Redrock-Prairie Creek herd (Fig. 2). Among the 83 calving events, 49 calves survived to four weeks of age (59%). Apparent calf survival was similar within the Narraway ($n = 28, 60\%$) and Redrock-Prairie Creek ($n = 21, 58\%$) herds ($p = 0.78, \chi^2 = 0.08, df = 1$, Pearson's Chi-squared Test). Apparent calf mortalities occurred 4 – 25 days post-parturition (median 12 days).

Sensitivity— At the 12 hour GPS-collar fix rate the consistency of predicting a calving event decreased sharply compared to more frequent fix schedules. This decline was caused by a loss of specificity, which is the ability to predict a non-calving event when it occurs (Fig. 3). This decrease in accuracy at 12 hours, was statistically significant when 4 hours was the standard ($p < 0.01, n = 99$, McNemar’s Chi-squared test), but not when 2 hours was the standard ($p = 0.08, n = 40$, McNemar’s Chi-squared test). The only significant decrease in consistency of detecting calf survival, using this methodology was at the 20 hour fix rate when compared to the 4 hour standard ($p = 0.02, n = 72$, McNemar’s Chi-squared test). Therefore, to avoid low accuracy of
predicting calving events and subsequent calf survival we only considered GPS-collars with a 1-6 hour fix rate for our analysis.

CALVING RANGE FIDELITY

GPS-collar data from two consecutive years were available for 34 caribou (15 Redrock-Prairie Creek, 19 Narraway). Of those 34 caribou, 18 had a calf in both years (53%), while 10 had a calf in one year (29%) and 6 had no calf in either year (18%). A greater proportion of collared Narraway caribou calved in consecutive years (68%) than Redrock-Prairie Creek caribou (33%). Narraway caribou appeared to have a lower probability of calving in one of two consecutive years (21%), or not calving at all (11%) when compared to Redrock-Prairie Creek caribou (single calf = 40%; no calf = 27%). The different patterns observed between herds was not statistically significant ($p = 0.12, \chi^2 = 4.21, df = 2,$ Pearson's Chi-squared Test).

We used the 18 observations of calving events in both years (5 Redrock-Prairie Creek, 13 Narraway) to assess calving range fidelity. The average distance between calving ranges, based on our fidelity metric, was 8.7 km (SD = 12.1 km, range = 0.7 – 49.7 km). Fidelity appeared greater within the Narraway herd (mean = 4.7 km, SD = 3.3 km) compared to the Redrock-Prairie Creek herd (mean = 19.2 km, SD = 20.0 km), however this difference was not statistically significant ($p = 0.09, W = 26,$ Wilcoxon rank sum test). We found evidence for a relationship between fidelity and seismic line density, with a seismic line density linear model having the highest $\text{AIC}_c$ weight (0.86, see Appendix B). The distance between calving ranges was farther (i.e., lower fidelity) when a caribou was exposed to higher seismic line density (Fig. 4). However, we identified the datum with the greatest distance between calving ranges (49.7 km) as a potential outlier. We removed the outlier and redid the analysis and still found evidence for a
seismic line density effect on calving range fidelity (Appendix B, Fig. 4). When we considered fidelity using only GPS-collar locations from the first day post-parturition, we observed the same pattern as for calving-range fidelity, although within the shorter time period calf range fidelity was slightly higher (mean = 7.4 km, SD = 11.8) based on a Wilcoxon signed rank test ($p = 0.03$, $W = 37$).

HABITAT SELECTION – CALVING SITE

The final calving site selection models at both scales had strong support with an AIC weight of 0.99 for the herd-range scale and 0.86 for the home-range scale (Appendix C). Both models included covariates for elevation, topographic position index, northness, roads and seismic lines with an additional effect of slope for the herd-range scale, and vegetation cover at the home-range scale. Regardless of scale, caribou selected calving sites at higher elevations especially on ridge-tops and upper slopes (Table 1). Caribou also selected south-facing aspects and avoided roads and seismic lines (Fig. 5, 6). At the herd-range scale caribou selected more gentle slopes. While at the home-range scale caribou selected mixed forest vegetation cover more than the reference category (closed conifer). The mean Spearman’s correlation coefficients from the k-fold cross-validation were 0.80 (range = 0.51 – 0.96) and 0.69 (range = 0.08 – 0.96) for the herd-range and home-range scales, respectively.

HABITAT SELECTION – POST-PARTURITION

Herd-Range Scale- At the herd-range scale, based on AIC rankings, the top post-parturition habitat selection models for both herds included the ‘base’ effects of vegetation cover, elevation, topographic position index, slope, northness and eastness. Considering disturbance covariates,
the top models included burned habitat and seismic lines as covariates for both herds, but roads were only included in the top model in the Narraway herd (Table 2).

In both herds female caribou with calves selected for regenerating vegetation cover and burned habitat at higher elevations. Both herds avoided areas with higher densities of seismic lines. Narraway caribou also selected terrain with a higher topographic position index (i.e., upper slopes and ridge-tops). Redrock-Prairie Creek caribou selected open conifer, mixed forest, herbaceous, bare and wetlands more than the reference category (closed conifer), and they also selected gentler slopes. Mean Spearman’s correlation coefficient from k-fold cross validation of the Narraway herd model was 0.88 (range = 0.67 – 1.00). Mean Spearman’s correlation coefficient from k-fold cross validation of the Redrock Prairie Creek herd model was 0.53, (range = -0.04 – 0.98).

**Home-Range Scale** - At the home-range scale, the final habitat selection models had the same covariates among both herds: elevation, topographic position index, slope, northness, and eastness as “base” covariates, and burns and roads as disturbance covariates.

In both herds, caribou with calves selected gentler slopes and avoided roads (Table 3, Fig. 7). Caribou in the Narraway herd, avoided burns and selected areas with higher TPI values (i.e., ridge-tops, upper slopes). Caribou in the Redrock-Prairie Creek herd selected burned habitat and south and west-facing slopes. The home-range scale models were good predictors of habitat selection based on Spearman’s correlation coefficient of the k-fold cross-validation for both Narraway (mean = 0.88, range = 0.15 – 1.00) and Redrock-Prairie Creek caribou (mean = 0.86, range = 0.47 – 1.00).
Discussion

We used a non-invasive method developed by DeMars et al. (2013) to estimate calving events and neonatal calf survival in two central mountain caribou herds in Western Alberta and Eastern British Columbia. This approach relies upon a dramatic and sustained drop in female movement rates indicative of parturition in ungulates (Long et al. 2009; Brook 2010). The method proved to be accurate when used to predict parturition (> 97%) and neonatal calf survival (87%) of boreal woodland caribou in British Columbia (DeMars et al. 2013). Although our results were not validated with known cow-calf survey data, the estimated calving dates (peak = 1 June, range = 21 May – 19 June,), calving rates (Narraway = 80%, Redrock-Prairie Creek = 61%), neonatal survival rates (Narraway = 60%, Redrock-Prairie Creek = 58%) and patterns of habitat selection were consistent with previous findings from field studies detailed below.

Across the 15 year study, we found that calving within the Narraway and Redrock-Prairie Creek central mountain caribou herds occurred from late May to early June with both herds experiencing peak calving dates within 24 hours of 31 May. These calving dates were consistent with those reported for a northern mountain herd (DU = 7) in British Columbia (peak = 28 May, range = 25 May–14 June, Gustine et al. 2006), and also similar to historical helicopter surveys completed by Edmonds (1988) within the Narraway and Redrock-Prairie Creek herds. Edmonds (1988) observed the first newborn calf on 5 June, and by 26 June all females had calves. The difference in calving period between Edmonds (1988) and this study may be due to the aerial surveys not commencing until 26 May and the long increment between flights (5 – 7 days). The estimated parturition rates (Narraway = 80%, Redrock-Prairie Creek = 61%) and neonatal calf survival rates (Narraway = 60%, Redrock-Prairie Creek = 58%) were similar to those reported for northern mountain and boreal caribou in Northern British Columbia (68% – 90% parturition,
56% – 67% survival, Gustine et al. 2006; DeMars et al. 2013), boreal caribou in Quebec (74% – 83% parturition, 31% – 70% survival, Pinard et al. 2012), and within the porcupine caribou in Alaska (21% – 59% survival, Adams et al. 1995; Jenkins and Barten 2005). Similar to previous research our calving site selection models demonstrated that females selected high elevation ridge-tops (Barten et al. 2001; Gustine and Parker 2008), and our models also agreed with historical observations of calving in this region occurring in the mountains instead of the foothills (Edmonds 1988; Edmonds and Smith 1991). These qualitative comparisons built confidence in the IBM results, but the DeMars et al. (2013) approach should continue to be evaluated quantitatively, our historic dataset precluded such an evaluation.

Calving at high elevations is believed to be a predator avoidance strategy used by mountain caribou (Bergerud and Page 1987; Leclere et al. 2012). This adaptation increases spatial separation between caribou and alternate prey like moose and deer that prefer lower elevation habitat (Bergerud et al. 1984; Jenkins and Wright 1988; Pauley et al. 1993), which correspondingly increases spatial separation between caribou and predators such as wolves (Whittington et al. 2011; DeCesare 2012). Previous research suggests that calving on steep slopes makes it more difficult for wolves to reach neonatal calves (Barten et al. 2001; Gustine et al. 2006; Steenweg 2011), and has been observed previously in mountain caribou (Gustine et al. 2006; Gustine and Parker 2008). We expected similar selection for steep slopes but on the contrary, we found that caribou selected flat or gentler slopes for calving. It is possible that caribou are selecting for gentler slopes for calving because calves can have trouble traversing steep slopes, which can lead to accidental falls and injuries (Bergerud et al. 1984). However, it is also possible that caribou may avoid steep slopes because of increased potential for overlap with predators such as wolverines in rugged terrain (Copeland et al. 2007; Fisher et al. 2013),
particularly during the wolverine denning season (Magoun and Copeland 2016). Although Gustine et al. (2006) thought it was unlikely that caribou were considering wolverine predation risk when selecting calving sites, they also found that wolverines were a major source of mortality for caribou calves less than 2 weeks of age (Gustine et al. 2006). High elevation and less steep slopes may expose caribou to increased predation risk from grizzly bears (McLellan and Hovey 2001; Apps et al. 2016), which can be major predator of caribou neonates (Gustine et al. 2006). However, locally this is unlikely because grizzly bear predate primarily on moose with caribou predation uncommon (Graham et al. 2016). It is likely that calving site and post-parturition selection is driven by trade-offs in predation risk from multiple predators (Leblond et al. 2016) and forage availability (Johnson et al. 2001; Avgar et al. 2015) but further analysis is needed to better understand these relationships.

We predicted caribou with calves would avoid anthropogenic features and burns because of the association between these features and low neonatal calf survival (Dussault et al. 2012; Leclerc et al. 2014), and because generally caribou avoid disturbances (Dyer et al. 2001; Joly et al. 2007; Vistnes and Nellemann 2008). Anthropogenic disturbances and burns promote early seral forest, which increases the density of alternative prey species (Bowman et al. 2010; DeCesare et al. 2010; Festa-Bianchet et al. 2011), driving a numerical response in predators (Bergerud 1988) and in turn increasing predation on caribou (Wittmer et al. 2005b; Vors et al. 2007; Sorensen et al. 2008; Robinson et al. 2010). In accordance with our prediction, we found that caribou avoided anthropogenic linear features (i.e., roads and seismic lines) during calving site selection and post-parturition. This is possibly a strategy to reduce their risk of encountering predators like wolves that select linear features (Latham et al. 2011; McKenzie et al. 2012), increasing encounters between wolves and caribou near linear features especially at higher
elevations during the calving season (Whittington et al. 2011). However, these results need to be interpreted with caution because human disturbances like roads and seismic lines were uncommon at higher elevations.

We found that burns had no detectable influence on calving site selection. However, during the post-parturition period, caribou in both herds selected burns at the herd-range scale, while at the home-range scale Narraway caribou avoided burns but Redrock-Prairie Creek caribou selected burns. Selection for burns was unexpected but may be explained by food resources playing a greater influence on space-use decisions than predator avoidance (Avgar et al. 2015). Previous research has found that burns (5 years of age) have a high vegetation productivity (Schaefer and Pruitt 1991), which may meet the nutritional demands of caribou during pregnancy and lactation (Parker et al. 2009). Confirmation of this hypothesis requires field assessments of food availability in burned areas of different ages, compared with other habitats within caribou range. Alternatively, our analysis could be overlooking the caribou habitat within unburned remnant patches within the perimeter of wildfires, because of spatial data limitations (Kansas et al. 2016).

We found a lower mean distance between consecutive calving ranges from year to year in the Narraway herd (5.2 km) than in the Redrock-Prairie Creek herd (19.2 km), although our comparison was limited by a small sample size \((n = 18)\) of collared caribou that calved in consecutive years. If we consider fidelity using a strict definition of returning to an area previously occupied (White and Garrott 1990), then calving site fidelity within our study was essentially non-existent. This low inter-annual fidelity has been reported among Eastern Migratory caribou (DU 4, Schaefer et al. 2000), southern mountain caribou (DU 9, Wittmer et al. 2006) and boreal caribou (DU 6, Courtois et al. 2007). Low fidelity to calving sites could be a
predator avoidance strategy, where caribou become less predictable and thus harder to locate from year to year (Gower et al. 2008). Furthermore, reducing fidelity as a predator avoidance strategy is consistent with our observation of lower calving range fidelity at higher seismic line densities because these features are associated with increased risk of wolf encounters during the spring calving period (Whittington et al. 2011). Ultimately low range fidelity may have negative fitness consequences among caribou because spatial memory is integral to space-use decisions (Avgar et al. 2015) and when ungulates are not familiar with their surroundings they can suffer from higher mortality (Forrester et al. 2015) and reduced foraging efficiency (Merkle et al. 2014).

Our research suggests prioritizing conservation of high elevation calving habitat for central mountain caribou, especially ridge-tops with flat or moderate slopes, and limiting linear feature development. Furthermore, the low fidelity to calving ranges from year to year predicates the need for conservation of large extents of suitable calving habitat to account for potential shifts in calving ranges (Faille et al. 2010), especially in areas with high seismic line densities. However, the fitness value of prioritizing conservation of calving habitat relative to other seasons needs to be evaluated (Gaillard et al. 2010). If calf mortality during the neonatal period is compensatory (Vaupel et al. 1979; Tveraa et al. 2003; Griffin et al. 2011), conservation of winter and migratory ranges may be of equal or greater importance in supporting long-term population persistence by contributing to adult survival and juvenile recruitment (Hebblewhite et al. 2007; DeCesare et al. 2012). Also, it should be noted that there may be no ideal calving habitat within a multi-predator ecosystem, instead caribou may have to make a series of trade-offs between low risk from one predator for higher risk from another (Gustine et al. 2006; Dussault et al. 2012; Leblond et al. 2016) while balancing nutritional requirements during lactation (Parker et al. 2009). Overall, our
application of a non-invasive approach (DeMars et al. 2013) to a long-term GPS-collar dataset provides important and new ecological information for endangered central mountain caribou (COSEWIC 2014). The continued use of adaptive and non-invasive approaches for exploring ecological questions for sensitive and declining species will better inform conservation measures, and can aid the recovery actions.
Acknowledgments

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TABLES

Table 1. Calving site selection model, odds ratios and 95% confidence intervals, among caribou (*Rangifer tarandus caribou*) within the Narraway and Redrock-Prairie Creek herds. Bold indicates odds ratios with confidence intervals not overlapping one. At the herd-range scale availability is defined as the entire herd range, and for the home-range availability is the home-range during the spring calving period. Additional variable details in Appendix A.

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<th></th>
<th>Open Conifer Forest</th>
<th>Deciduous Forest</th>
<th>Mixed Forest</th>
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<th>Bare</th>
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<td>0.61 (0.43 – 0.85)</td>
<td>0.04 (0.01 – 0.26)</td>
<td>0.13 (0.03 – 0.57)</td>
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* Odds ratio represents a 100 unit increase
Table 2. The herd-range scale, odds ratios and 95% confidence intervals for post-parturition habitat selection models among caribou (*Rangifer tarandus caribou*) within the Narraway and Redrock-Prairie Creek (RPC) herds. Bold indicates odds ratios with confidence intervals not overlapping one. Additional variable details in Appendix A.

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<th>Bare</th>
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<td>0.73 (0.46 – 1.14)</td>
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<td><strong>RPC</strong></td>
<td><strong>0.97 (0.69 – 1.36)</strong></td>
<td>1.13 (0.66 – 1.95)</td>
<td><strong>0.34 (0.19 – 0.58)</strong></td>
<td><strong>0.58 (0.33 – 1.00)</strong></td>
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<td><strong>0.66 (0.43 – 1.00)</strong></td>
<td><strong>2.78 (1.38 – 5.59)</strong></td>
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<td>0.95 (0.78 – 1.14)</td>
<td><strong>2.43† (1.71 – 3.45)</strong></td>
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<td><strong>0.10 (0.02 – 0.55)</strong></td>
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<tr>
<td><strong>RPC</strong></td>
<td><strong>3.45 (1.06 – 11.27)</strong></td>
<td><em><em>0.90</em> (0.67 – 1.22)</em>*</td>
<td><strong>0.99 (0.98 – 1.00)</strong></td>
<td>0.92 (0.73 – 1.16)</td>
<td>0.89 (0.70 – 1.12)</td>
<td><strong>1.61† (1.15 – 2.25)</strong></td>
<td>--</td>
<td><strong>0.23 (0.09 – 0.58)</strong></td>
</tr>
</tbody>
</table>

* Odds ratio represents a 100 unit increase

† Odds ratio represents a 0.10 unit increase
Table 3. The home-range scale, odds ratios and 95% confidence intervals for post-parturition habitat selection models among caribou (*Rangifer tarandus caribou*) within the Narraway and Redrock-Prairie Creek (RPC) herds. Bold indicates odds ratios with confidence intervals not overlapping one. Additional variable details in Appendix A.

<table>
<thead>
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<th></th>
<th>Elevation</th>
<th>TPI&lt;sub&gt;k&lt;/sub&gt;</th>
<th>Slope</th>
<th>Northness</th>
<th>Eastness</th>
<th>Burn&lt;sub&gt;70&lt;/sub&gt;</th>
<th>DRoad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Narraway</td>
<td>0.54</td>
<td><em>1.97</em></td>
<td>0.98</td>
<td>0.85</td>
<td>0.97</td>
<td>0.65</td>
<td>3.28</td>
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<tr>
<td></td>
<td>(0.22 – 1.33)</td>
<td>(1.59 – 2.45)</td>
<td>(0.97 – 0.98)</td>
<td>(0.70 - 1.02)</td>
<td>(0.84 - 1.12)</td>
<td>(0.49 – 0.85)</td>
<td>(1.88 – 5.75)</td>
</tr>
<tr>
<td>RPC</td>
<td>0.94</td>
<td><em>1.26</em></td>
<td>0.97</td>
<td>0.67</td>
<td>0.73</td>
<td>5.58</td>
<td>1.61</td>
</tr>
<tr>
<td></td>
<td>(0.28 – 3.09)</td>
<td>(0.93 – 1.71)</td>
<td>(0.96 – 0.98)</td>
<td>(0.55 – 0.81)</td>
<td>(0.59 – 0.89)</td>
<td>(3.73 – 8.35)</td>
<td>(1.25 – 2.07)</td>
</tr>
</tbody>
</table>

* Odds ratio represents a 100 unit increase
Figure Captions

Fig. 1. Overview of the study area which encompasses the Narraway and Redrock-Prairie Creek caribou (Rangifer tarandus caribou) ranges in Western Alberta and Eastern British Columbia, Canada.

Fig. 2. Cumulative percentage of calves born among female caribou (Rangifer tarandus caribou) in the Narraway and Redrock-Prairie Creek herds in Western Alberta and Eastern British Columbia, Canada. Parturition was inferred based on a sudden reduction in movement using a method developed by DeMars et al. (2013).

Fig. 3. The accuracy, sensitivity and specificity of the DeMars et al. (2013) IBM method to estimate a calving event and apparent neonatal calf survival among central mountain caribou (Rangifer tarandus caribou) in Western Alberta and Eastern British Columbia, at varying GPS-collar fix rates. The IBM results at the two or four hour fix rate were considered as the standard against which other fix rates were compared because the actual calving events and subsequent survival to four weeks of age were unknown.

Fig. 4. The linear relationship between caribou calving range fidelity and seismic line density among central mountain caribou (Rangifer tarandus caribou) in Western Alberta and Eastern British Columbia. Fidelity was calculated as the mean distance between all GPS-collar locations in two consecutive years during the post-parturition period (calf up to four weeks old). Seismic line density was quantified within a 5-km radius, averaged across all GPS-collar locations during the first of two consecutive calving years.
Fig. 5. Relative probability of a caribou (*Rangifer tarandus caribou*) selecting a calving site based on landscape features available throughout the herd-range, among the Narraway and Redrock-Prairie Creek herds.

Fig. 6. Relative probability of a caribou (*Rangifer tarandus caribou*) selecting a calving site based on landscape features available within an individual spring home-range, among the Narraway and Redrock-Prairie Creek herds.

Fig. 7. Habitat selection during the post-parturition calving period (0 to 4 weeks of age) among GPS-collared female caribou (*Rangifer tarandus caribou*) that gave birth to a calf. Habitat selection models were constructed among the Narraway and Redrock-Prairie Creek herds in Western Alberta and Eastern British Columbia. Displayed are habitat selection models specific to each herd, therefore values were binned into five equal area bins that reflect the rank of RSF values for ease of visual comparison.
Cumulative percentage of calves born among female caribou (Rangifer tarandus caribou) in the Narraway and Redrock-Prairie Creek herds in Western Alberta and Eastern British Columbia, Canada. Parturition was inferred based on a sudden reduction in movement using a method developed by DeMars et al. (2013).

Fig. 2
144x91mm (300 x 300 DPI)
The accuracy, sensitivity and specificity of the DeMars et al. (2013) IBM method to estimate a calving event and apparent neonatal calf survival among central mountain caribou (Rangifer tarandus caribou) in Western Alberta and Eastern British Columbia, at varying GPS-collar fix rates. The IBM results at the two or four hour fix rate were considered as the standard against which other fix rates were compared because the actual calving events and subsequent survival to four weeks of age were unknown.

Fig. 3
139x139mm (300 x 300 DPI)
The linear relationship between caribou calving range fidelity and seismic line density among central mountain caribou (Rangifer tarandus caribou) in Western Alberta and Eastern British Columbia. Fidelity was calculated as the mean distance between all GPS-collar locations in two consecutive years during the post-parturition period (calf up to four weeks old). Seismic line density was quantified within a 5-km radius, averaged across all GPS-collar locations during the first of two consecutive calving years.

Fig. 4

139x228mm (300 x 300 DPI)