Appendix A: Identifying calving sites – detailed methods and results

A.1 Identifying caribou calving sites

We used the individual based method (IBM) of DeMars et al. (2013) to estimate the timing and locations of calving events and calf survival. The IBM modeling approach uses movement patterns of individuals to identify sudden and marked reductions from normal movement patterns; these are termed 'break points'. Break points are based on three movement models: i) did not calve – M0; ii) calved and calf survived to 4 weeks – M1; and iii) calved with subsequent calf loss prior to 4 weeks – M2; Figure A1). The initial break point when the movement of the adult female caribou decreases (BP1) is linked to a particular GPS record, which is the assumed calving site. The second break point (BP2) is associated with the timing and location of the presumed calf mortality. Further details of the IBM approach can be found in DeMars et al. (2013) and additional details of our analysis were previously described in Poole et al. (2018).

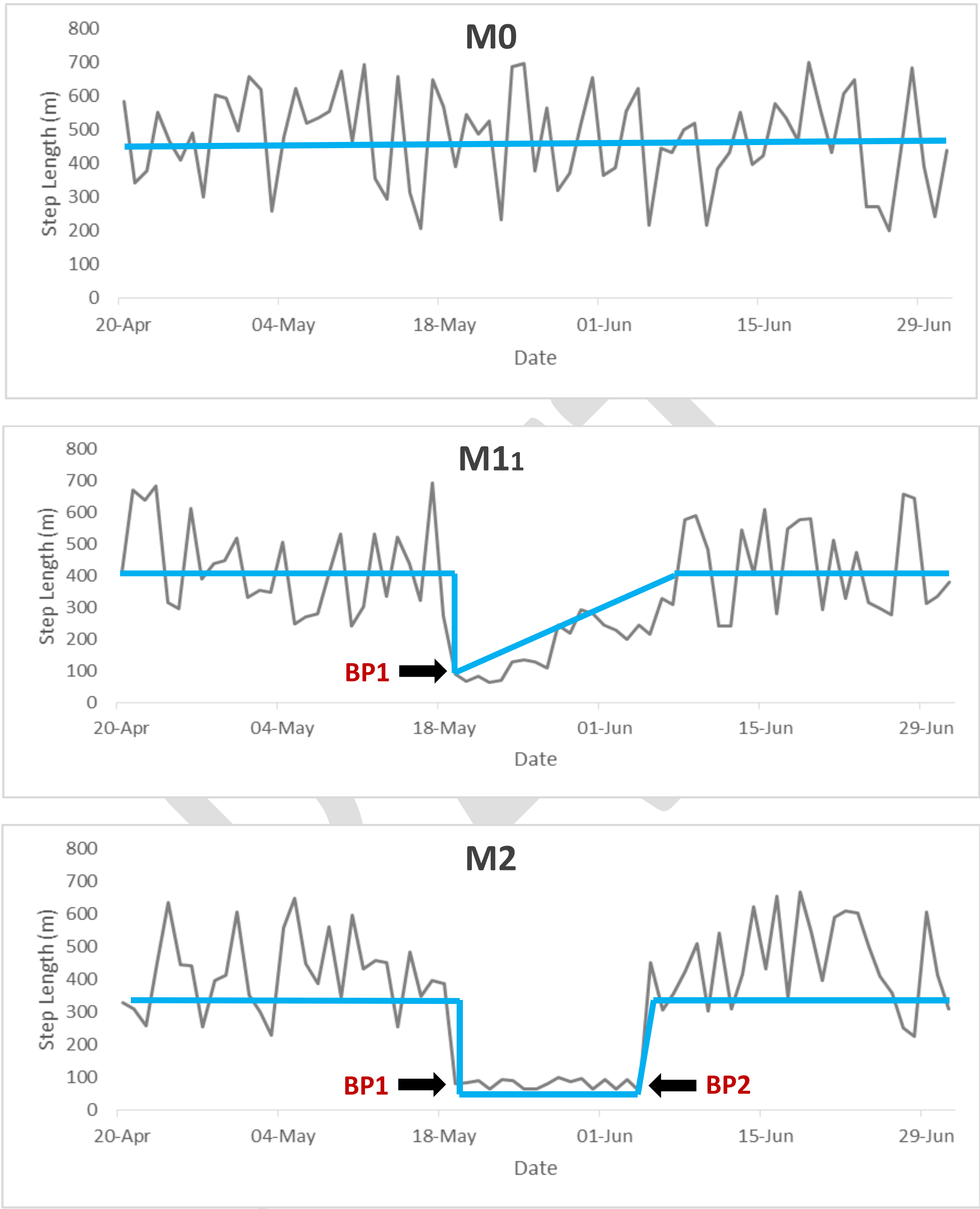

Figure A.1. Examples of movement models representing the three movement states of female caribou during the calving season identified using the individual-based method: caribou did not calve (M0), caribou calved and the calf survived (M1), and caribou calved and the calf died (M2). Break points associated with the estimated calving event (BP1) and calving mortality (BP2) are also shown.

A.2. RESULTS

Table A.1. Summary of results from individual based (IBM) analysis of adult female caribou GPS location data during the calving season using to identify calving events and calf survival (Status, Calving Date, Calf Lost Date) for the Little Smoky caribou herd, Alberta, Canada, between 2000 and 2015.

Year	ID	Fix Rate Success	Status	Calving Date	Calf Lost Date
2015	C2240	0.98	Did not calve	-	-
2015	C2241	0.98	Calved; calf died	05/10/2015	05/29/2015
2015	C2242	0.99	Calved; calf died	05/15/2015	06/06/2015
2015	C2187	0.97	Calved; calf survived	05/12/2015	-
2014	C2187	0.97	Calved; calf survived	05/20/2014	-
2015	C2188	0.97	Did not calve	-	-
2014	C2188	0.97	Calved; calf died	05/27/2014	05/31/2014
2015	C2189	0.99	Calved; calf survived	05/18/2015	-
2014	C2189	0.98	Calved; calf died	05/24/2014	05/28/2014
2015	C2190	0.98	Did not calve	-	-
2014	C2190	0.98	Calved; calf died	05/30/2014	06/05/2014
2015	C2191	0.98	Calved; calf died	05/25/2015	05/31/2015
2014	C2191	0.98	Calved; calf survived	05/17/2014	-
2010	C1516	0.89	Calved; calf survived	05/19/2010	-
2009	C1516	0.94	Calved; calf died	05/24/2009	06/07/2009
2010	C1089	0.86	Calved; calf died	05/25/2010	06/27/2010
2009	C1089	0.9	Calved; calf survived	05/30/2009	-
2008	C1089	0.88	Calved; calf died	05/19/2008	05/28/2008
2007	C1089	0.89	Did not calve	-	-
2009	C1524	0.89	Calved; calf survived	06/03/2009	-
2008	C1353	0.89	Calved; calf survived	05/23/2008	-
2008	C1091	0.89	Did not calve	-	-
2007	C1091	0.88	Calved; calf survived	05/29/2007	-
2008	C1092	0.93	Did not calve	-	-
2007	C1092	0.88	Did not calve	-	-
2007	C1090	0.87	Calved; calf survived^	05/15/2007	-
2007	C1093	0.94	Calved; calf died	05/20/2007	06/02/2007
2005	C960	0.87	Calved; calf survived	05/09/2005	-
2005	C964	0.60	Calved; calf died	05/25/2005	06/04/2005
2005	C1015	0.88	Calved; calf survived	05/14/2005	-
2005	C1024	0.73	Calved; calf survived	05/17/2005	-
2005	C1034	0.71	Calved; calf survived	05/22/2005	-
2005	C1035	0.60	Did not calve	-	-
2004	C1009	0.72	Calved; calf died	05/22/2004	05/25/2004

2003	C1009	0.76	Calved; calf died	05/20/2003	05/30/2003
2004	C1017	0.78	Calved; calf survived	05/13/2004	-
2003	C1017	0.82	Calved; calf survived	05/26/2003	-
2004	C1010	0.66	Calved; calf survived	05/30/2004	-
2003	C1010	0.61	Calved; calf died	05/21/2003	06/04/2003
2004	C1012	0.87	Calved; calf died	05/12/2004	05/22/2004
2003	C1012	0.88	Calved; calf died	05/20/2003	05/24/2003
2004	C1019	0.87	Calved; calf survived	05/25/2004	-
2004	C1022	0.89	Calved; calf survived	05/27/2004	-
2004	C1023	0.85	Calved; calf died	05/27/2004	06/05/2004
2004	C1026	0.79	Calved; calf survived	05/22/2004	-
2004	C1027	0.66	Calved; calf survived	05/27/2004	-
2003	C992	0.78	Did not calve	-	-
2002	C992	0.76	Calved; calf died	05/22/2002	06/02/2002
2003	C1011	0.87	Calved; calf survived	05/23/2003	
2003	C1083	0.97	Calved; calf died	05/15/2003	05/16/2003
2002	C989	0.89	Did not calve	-	-
2002	C994	0.71	Did not calve	-	-
2002	C995	0.74	Calved; calf died	06/08/2002	07/01/2002
2002	C996	0.55	Calved; calf died	05/27/2002	06/03/2002
2002	C990	0.66	Calved; calf died	05/23/2002	06/13/2002
2002	C984	0.86	Calved; calf died	05/22/2002	06/03/2002
2001	C966	0.85	Calved; calf died	05/24/2001	06/05/2001
2000	C966	0.65	Calved; calf died	05/19/2000	05/25/2000
2000	C963	0.75	Calved; calf died	05/23/2000	06/10/2000

Table A.2. Summary of results from individual based (IBM) analysis of adult female caribou GPS location data during the calving season using to identify calving events and calf survival (Status, Calving Date, Calf Lost Date) for the Chinchaga caribou herd, Alberta and British Columbia, Canada, between 2004 and 2009.

Year	ID	Fix Rate Success	Status	Calving Date	Calf Lost Date
2009	C1520	0.90	Calved; calf survived	5/17/2009	-
2009	C1521	0.95	Calved; calf survived	5/13/2009	-
2009	C1522	0.93	Calved; calf survived	5/14/2009	-
2009	C1224	0.95	Calved; calf survived	5/12/2009	-
2008	C1224	0.96	Calved; calf died	5/24/2008	6/6/2008
2009	C1225	0.95	Calved; calf survived	5/7/2009	-
2008	C1225	0.97	Calved; calf died	5/10/2008	5/14/2008
2009	C1226	0.95	Calved; calf survived	5/12/2009	-
2008	C1226	0.91	Calved; calf died	4/25/2008	5/3/2008
2009	C1228	0.95	Calved; calf survived	5/14/2009	-
2008	C1228	0.95	Calved; calf died	6/1/2008	6/6/2008
2009	C1229	0.97	Did not calve	-	-
2008	C1229	0.96	Calved; calf died	5/26/2008	5/30/2008
2009	C1230	0.94	Calved; calf survived	5/11/2009	-
2008	C1230	0.95	Calved; calf survived	5/28/2008	-
2009	C1233	0.94	Calved; calf survived	5/4/2009	-
2008	C1233	0.95	Calved; calf died	5/8/2008	6/3/2008
2008	C1234	0.81	Calved; calf survived	5/6/2008	-
2007	C1234	0.93	Calved; calf died	5/15/2007	6/14/2007
2007	C1235	0.80	Calved; calf died	5/9/2007	5/17/2007
2007	C1236	0.97	Did not calve	-	-
2007	C1237	0.96	Did not calve	-	-
2007	C1238	0.96	Calved; calf died	5/18/2007	6/1/2007
2005	C152.341	76.09	Calved; calf survived	05/12/2005	-
2004	C152.341	89.37	Calved; calf died	05/23/2004	06/03/2004
2004	C152.019	0.85	Did not calve	-	-
2004	C152.027	0.85	Did not calve	-	-
2004	C152.039	0.76	Did not calve	-	-
2004	C152.049	0.78	Calved; calf survived	05/03/2004	-
2004	C152.070	85.60	Did not calve	-	-
2004	C152.120	93.21	Calved; calf died	05/21/2004	05/30/2004
2004	C152.209	89.95	Calved; calf died	05/07/2004	05/17/2004

Appendix B: Explanatory variables

The habitat and topographic variables that we used to build models of habitat selection are shown in Table B.1. For habitat, we used landcover derived from LandSat imagery captured in 2000 (Canadian Forest Service Earth Observation for Sustainable Development of Forest (EOSD) cover map; Natural Resources Canada 2009) which we re-classified and combined into 5 categories for data analysis: 1) conifer forest, 2) shrub and herb, 3) alpine, 4) mixed and broadleaf forest, and 5) water and wetlands. Using a 30m x 30m resolution digital elevation model (DEM), we extracted values of elevation, aspect, slope, terrain wetness (compound topographic index, CTI; Gessler et al. 2000), and topographic position index (TPI); positive TPI values indicate ridges or hilltops, while negative values represent valley bottoms (Jenness, 2006). We calculated aspect as indices of eastness and northness (Gustine et al., 2006b; Nobert et al., 2016).

For wildfires, pipelines, roads, wellsites, and seismic lines, we used open-source provincial datasets from Alberta and British Columbia. For wildfires, we only included wildfire ≤ 60 years old in our analysis. We were interested in the separate influences of pipelines, roads, and seismic lines on caribou, however, many pipelines within our study area are immediately adjacent to roads. Therefore, to isolate the influence of pipelines on caribou predation risk, we generated a pipeline dataset for the Little Smoky caribou range that excluded pipelines within 30m of roads. In the Chinchaga range, all pipelines were within 30m of roads, therefore we excluded pipelines from the Chinchaga analysis. For seismic lines, we only considered conventional seismic lines (> 5m in width) in our analysis in the Little Smoky caribou ranges. We were unable to acquire seismic line data for portion of the Chinchaga range that falls within British Columbia, therefore we excluded seismic lines from the Chinchaga analysis. For cutblocks, we used data provided by Alberta Forest Management Agreement (FMA) holders within our study area and open source data for British Columbia; we included cutblocks ≤ 30 years old in our analysis. Because landscape change within the study area was ongoing, we generated annual datasets for wildfire, pipelines, roads, wellsites, and cutblocks, (2000 to 2015). All conventional seismic lines (hereafter "seismic lines") in our study area were constructed prior to 2006, therefore we generated a single dataset for seismic lines that was applied across all years of analysis.

For predators, we used coefficients available from within our study area (DeCesare et al., 2014; Nielsen, 2007) or coefficients available from areas adjacent to our study area (MacNearney et al., 2016; Scrafford et al., 2017) to map predator occurrence. We also developed a black bear habitat selection model using data collected in an area adjacent to the Chinchaga range (DeMars and Boutin, 2018, 2017) and used the resulting coefficients to map black bear occurrence in the Chinchaga range. Details of predator RSFs are in Chapter 4 and the black bear RSF is described in Appendix D. We calculated predator RSFs at three scales: 90m, 1km, and 5km (Table B.1).

Table B.1. Variables used to assess calving site and season habitat selection ('Calving'), calf survival habitat selection ('Calf fate') for Little Smoky and Chinchaga caribou herds, in Alberta and British Columbia, Canada, between 2000 and 2015. Variables used to build caribou calving season black bear habitat selection models in north-eastern British Columbia in 2013 and 2014 are also shown (see Appendix D for details). All raster data were 30 x 30 m resolution.

Variable	Description	Calving	Calf fate	Black bear
Disturbance				
Road_	Density of roads within 90m, 1km, and 5km radius (km/km^2)	x	x	x
Pipe_	Density of pipelines not adjacent to roads within 90m, 1km, and 5km radius (km/km^2)	x	x	x
Seismic_	Density of seismic lines within 90m, 1km, and 5km radius (km/km^2)	x	x	-
Cutblock_	Density of cutblocks within 90m, 1km and 5km radius (km^2/km^2)	x	x	x
Fire_	Density of areas affected by forest fires 60 years or younger within 90m, 1km and 5km radius (km^2/km^2)	x	x	-
Well_	Density of wellsites within 90m, 1km and 5km radius ($wellsites/km^2$)	x	x	x
Terrain				
Elevation	Digital elevation model, a measure of elevation (m)	x	x	-
Slope	Terrain slope (°)	x	x	-
Wetness (CTI)	Compound topographic index; measure of soil wetness, unitless	x	x	-
TPI	Topographic Position Index; difference in elevation (m) between a central cell and the mean elevation within a 30m radius, unitless	x	x	-
Eastness	Cosine of aspect (rad), -1 to +1	x	x	-
Northness	Sin of aspect (rad), -1 to +1	x	x	-
Landcover[a]				
Alpine	Glacier, snow, ice, talus	x	x	-
Water and Wetland	Water/Wetland: Land with water table near or above soil surface for enough time to promote wetland	x	x	x
Shrub herb	At least 20% ground cover, vascular plants with and without woody stem	x	x	x
Conifer	Coniferous trees are 75% or more of total basal area.	x	x	x
Mixed and broadleaf	Combined category of mixed forest and broadleaf forest; mixedwood: neither coniferous or broadleaf account for 75% or more of total basal area; broadleaf: broadleaf trees are 75% or more of total basal area.	x	x	x
Predator RSFs				
Wolf_	Resource selection function for wolves during summer (Little Smoky) or denning (Chinchaga) seasons within 90m, 1km, and 5km radius	-	x	-
Grizzly bear_[b]	Resource selection function for grizzly bears – maximum of spring and summer within 90m, 1km, and 5km radius	-	x	-
Cougar_[b]	Resource selection function for cougars – annual within 90m, 1km, and 5km radius	-	x	-
Black bear_[c]	Resource selection function for black bears during the caribou calving season within 90m, 1km, and 5km radius	-	x	-
Wolverine_[c]	Resource selection function for wolverines – maximum of male and female values during summer within 90m, 1km, and 5km radius	-	x	-

[a] Descriptions of landcover adapted from EOSD (Natural Resources Canada, 2009); [b]Little Smoky only; [c]Chinchaga only

APPENDIX C: CALVING SITE AND CALVING SEASON HABITAT SELECTION – DETAILED METHODS

We constructed resource selection functions (RSFs) for calving site and post-parturition habitat selection using a use-available design (Manly et al., 2002). As scale is important to consider when modeling caribou habitat selection (DeCesare et al., 2012; Schaefer et al., 2000), we examined selection at two scales: i) herd-range scale (second order selection) and ii) home-range scale (third order selection) (Johnson et al., 2006).

C.1. CALVING SITE SELECTION

For calving site RSFs, we assessed calving locations as determined in the IBM process described in A.1. We sampled 20 random locations from each provincial herd boundary (herd-range scale) and from each individual's home range (home-range scale), defining home range as the minimum convex polygon (MCP) enclosing all GPS telemetry locations for that individual during the calving season (15 April – 15 July). We extracted habitat covariates (see Table B.1) to calving locations (i.e., used locations) and random locations (i.e., available locations), and compared habitat covariates at used versus available locations using generalized linear mixed models (GLMM). We specified Animal ID-year specified as a random effect to account for individual-based correlation and unbalanced sample sizes resulting from variable fix rates between individuals (Bolker et al., 2009; Fieberg et al., 2010; Gillies et al., 2006). We fit models using the R package 'lme4' (Bates et al., 2015) in R (R Development Core Team, 2015). Before fitting models we assessed correlation among explanatory covariates and removed any one of 2 variables correlated at ≥ 0.6; using univariate analysis and Akaike's Information Criterion (AIC; (Burnham, 2004; Burnham and Anderson, 2002) to identify which of the pair of variables was most influential for downstream analysis. We also used univariate analysis and AIC to identify the most influential scale for each disturbance variable (90m, 1km, or 5km). Also, because moderate collinearity can be problematic when investigating ecological signals, we removed any covariates with a variance inflation factor > 3 (Zuur et al., 2010, 2009).

Our objective was to optimize model fit rather than test competing hypotheses; therefore, we first assessed resource selection within each category of variables (landcover, terrain, disturbance) and used AIC (Burnham, 2004; Burnham and Anderson, 2002) within the drop1 function in the R package 'stats' to retain only influential variables within each of the categories of variables (R Development Core Team, 2015). Once we identified influential variables within each category, we fit a global model that included all the influential variables combined. Finally, we followed the principle of parsimony and used the drop1 function a final time to remove any non-influential variables from the global model for each season. We present results as beta coefficients (β) and lower and upper 95% confidence intervals (LCL, UCL), where positive values indicate that a variable is selected more than expected when compared to a random distribution, and negative values indicate that a habitat or topographic variable is selected less than expected when compared to a random distribution. For mapping, we present results as the relative probability of selection (expβ/1+expβ). We evaluated the predictive ability of final models using k-fold cross validation (Boyce et al., 2002), randomly partitioning data into 20% testing and 80% training datasets and calculating the mean, minimum and maximum spearman rank correlations between fitted and predicted values (r_s) across 100 iterations. Values of r_s closer to 1 indicate better predictive power of a model.

C.2. Calving season habitat selection

We also used GLMMs to assess post-parturition habitat selection of caribou during the calving season. At the herd-range scale, we compared caribou GPS locations (used locations) to randomly sampled available locations within provincial herd range boundaries. At the home-range scale, we compared used locations to available locations within each individual caribou's home range. Home ranges were defined as minimum convex polygons (MCP) encompassing locations for that individual across the spring season, starting at one day past the calving date for an individual and ending with the death of a calf or 28 days after calving event (DeMars et al., 2013). At the herd- and home-range scales we generated 20 available locations per used location to ensure that model coefficients were consistently stable (Northrup et al., 2013). We fit and evaluated models using the approach outlined for calving site analysis. We present results as beta coefficients (β) and lower and upper 95% confidence intervals (LCL, UCL), where positive values indicate that a variable is selected more than expected when compared to a random distribution, and negative values indicate that a habitat or topographic variable is selected less than expected when compared to a random distribution. We also present results as the relative probability of selection. We evaluated the predictive ability of final models using k-fold cross validation.

Appendix D: Black bear habitat selection in north-eastern British Columbia

D.1. Methods

To build black bear habitat selection models we used GPS data collected during the caribou calving season in north-eastern British Columbia in 2012 and 2013 (DeMars and Boutin, 2018, 2017). The GPS data were collected adjacent to the Chinchaga boreal caribou range; therefore, habitat selection models built for that area likely approximate black bear habitat selection within the Chinchaga caribou range. Data were collected from 19 individuals. Further details about black bear GPS data and capture and handling can be found in DeMars and Boutin (2018).

At the home-range scale, we compared used locations (actual GPS locations) to available locations within each individual bear's caribou-calving season home-range, defined as minimum convex polygons (MCPs) encompassing locations for that individual across the calving season. We generated 20 available locations per used location (Northrup et al., 2013). We generated MCPs and available locations using Geospatial Modelling Environment (GME, Beyer, 2012), extracted habitat and disturbance variables (see Table B.1) to used and available locations using the R package 'raster' (Hijmans, 2014), and built habitat selection models (GLMMs) using the R package 'lme4' (Bates et al., 2015) in R (R Development Core Team, 2015); specifying black bear Animal ID as a random effect (Bolker et al., 2009; Fieberg et al., 2010; Gillies et al., 2006). The habitat and disturbance variables used to build models of habitat selection are shown in Table B.1. We fit and validated models using identical methods to those used to fit caribou habitat selection models (see Appendix C). We present results as beta coefficients (β) and lower and upper 95% confidence intervals (LCL, UCL).

D.2. RESULTS

At the home-range scale, during the caribou calving season, black bears selected areas with higher densities of roads, cutblocks, and wellsites, and also selected mixed and broadleaf forest and shrub and herb landcover (Table D.1). K-fold cross validation indicated excellent predictive power for the model (Table D.1).

Table D.1. Parameter estimates (β) and lower and upper 95% confidence intervals (LCL, UCL) for generalized linear mixed models used to identify factors determining black bear caribou calving season habitat selection at the home-range scale in north-eastern British Columbia, Canada in 2012 and 2013. Mean, minimum, and maximum r_s values from K-fold cross validation are also shown. Variables are described in Table B.1.

	β	LCL	UCL
Intercept	-3.39	-3.43	-3.35
Road 90m	3.35	3.25	3.45
Cut 90m	0.35	0.27	0.43
Well 90m	3.25	3.03	3.47
Mixed and broadleaf	0.47	0.43	0.51
Shrub herb	0.20	0.14	0.26
Mean r_s (min, max)	0.96 (0.81, 1)		

APPENDIX E: LINKING HABITAT SELECTION AND PREDATION RISK TO CALF SURVIVAL

E.1. METHODS

We used GLMMs to assess latent selection differences (Latham et al., 2013b) between caribou that lost calves and caribou with calves that lived, using calf fate as the response variable (lost = 1, lived = 0). We included the caribou fate pair as a random effect within models and built models using the same approach outlined for calving site and calving season selection (see Appendix C). We generated 100 datasets, each with a different random pairing between caribou with calves that lived and caribou that lost calves, and used AIC to identify the most informative variables to include within final models. For AIC we used an identical approach to that used for other habitat selection models (see Appendix B), but including a random effect for each caribou pair and dataset (dataset1…100). Once we identified the most informative variables to carry forward to the final model, we then fit final models to each of the 100 datasets using the R packages 'lme4' (Bates et al., 2015) and 'plyr' (Wickham, 2010). We report results as the mean beta coefficients and lower and upper 95% confidence intervals averaged across all 100 models.

E.2. RESULTS

Table E.1. Mean parameter estimates (β) and lower and upper 95% confidence intervals (LCL, UCL) for generalized linear mixed models used to identify factors determining calving fate in the Little Smoky herd in west-central Alberta, Canada, between 2000 and 2015. Models compared locations of caribou whose calf lived to those that lost calves across 100 iterations. Shown are models including grizzly bears and cougars; the wolf model is in Table 5.1. The reference category for calf fate was 'calf lived'. Variables are described in Table B.1.

	Grizzly bear			Cougar		
	β	LCL	UCL	β	LCL	UCL
Intercept	-3.27	-23.89	17.35	5.65	4.72	6.58
Pipe 1km	-	-	-	0.04	-0.34	0.43
Seismic 90m	-	-	-	-	-	-
Seismic 1km	0.39	-0.09	0.87	0.21	0.16	0.25
Cut 1km	-	-	-	26.10	21.80	30.41
Slope	0.43	0.24	0.62	-0.03	-0.06	-0.01
TPI	0.43	-0.65	3.09	-2.82	-3.03	-2.60
Grizzly bear 1km	2.25	1.32	3.18	-	-	-
Cougar 1km	-	-	-	-2.11	-2.36	-1.87

Table E.2. Mean parameter estimates (β) and lower and upper 95% confidence intervals (LCL, UCL) alternate generalized linear mixed models used to identify factors determining calving season habitat selection of caribou with calves that lived in the Chinchaga herd in west-central Alberta, Canada, between 2004 and 2009. Models compared locations of caribou whose calf lived to those that lost calves across 100 iterations. Shown are models including wolverines and black bears; the wolf model is in Table 5.2. Variables are described in Table B.1.

	Wolverine			Black bear		
	β	LCL	UCL	β	LCL	UCL
Intercept	-2.52	-4.80	-0.23	11.15	7.88	14.43
Elevation	6.94	4.68	9.21	2.59	0.74	4.43
TPI	-0.04	-0.06	-0.01	-0.04	-0.06	-0.01
Mixed and broadleaf	-1.67	-2.27	-1.06	-1.46	-2.07	-0.85
Wolverine 5km	-1.06	-1.49	-0.62	-	-	-
Black bear 5km	-	-	-	-4.37	-5.14	-3.59

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