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ANALYSIS OF THE EFFECTS OF THE INUVIK-TUKTOYAKTUK HIGHWAY ON BARREN-GROUND CARIBOU

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ABSTRACT

Highway 10, the Inuvik-Tuktoyaktuk Highway (ITH) is an all-season road which crosses the winter ranges of the Cape Bathurst and Tuktoyaktuk Peninsula barren-ground caribou herds. Of interest is whether the presence of the ITH, which was built from 2014-2017, has affected barren-ground caribou habitat selection and distribution relative to the highway. Collar data from the Tuktoyaktuk Peninsula and Cape Bathurst herds during the fall, winter, and spring was used for this analysis based upon when these caribou were in the vicinity of the road. The collar data spans from years prior to the road (2005-2014), during the time of road building (2014-2016) and after the road was open (2017-2020), allowing a before and after comparison of habitat selection relative to the road. In general, the seasonal ranges of the herds were to the northeast of the road with movements across the road occurring in the upper half of the road area.

A habitat selection model was developed that predicted caribou distribution relative to the proposed road based on habitat and geographic variables. Habitat selection was compared before and after road completion at different distances from the road to infer if caribou selection and distribution changed with the implementation of the road. The results from this analysis suggested that caribou were less likely to select habitats immediately to the east of the road (2 km) and approximately 10 km to the west of the road after the road was built.

One likely mechanism of reduced selection on the west side of the road was a reduced probability of caribou crossing the road when moving in from the northeast. To explore this mechanism further, a logistic regression model was applied that assessed the probability of a caribou crossing the road as a function of distance to the road (using the intended route of the road pre-construction) and whether the road was built. The probability of caribou crossing the road decreased after the road was completed. These results suggest that the road has impacted caribou range use to the west of the road. Further methods to assess the impact of the road and assess potential mitigation strategies are discussed.

These analyses are limited by the current reduced caribou numbers for the herds using the area. If herd numbers increase, and herd range expands back to historically used areas, there will likely be more barren-ground caribou in proximity to and crossing the ITH.

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INTRODUCTION

Highway 10, the Inuvik-Tuktoyaktuk Highway (ITH) crosses the winter ranges of the Cape Bathurst and Tuktoyaktuk Peninsula barren-ground caribou herds (ACCWM 2014). Construction of this all-season road began in 2014, and it was officially opened in November 2017. Predicted impacts of the ITH on caribou included the displacement of caribou from the proximity of the road, potential reduced survival in the proximity of the road, and the potential for the road to be a barrier to movement. Numerous studies have linked roads, and the accompanying disruption of migration corridors, to population decline and reduced harvest yield in ungulate populations (Berger 2004, Bolger et al. 2008, Van Moorter et al. 2020). In particular, infrastructure with variable permeability, such as roads, have been demonstrated to influence movement patterns for caribou (Nellemann and Cameron 1996) as well as other ungulate species (Thirgood et al. 2004, Runge et al. 2014, Sawyer et al. 2017).

As part of the wildlife effects monitoring program for the ITH, data from collared caribou was collected prior to, during, and after the construction of the highway to monitor caribou movement, habitat selection, and mortality, and to assess whether these have changed in response to the road.

This report presents analyses that assess habitat selection and movements of caribou prior to building and after the road was built. The objectives of this analysis were as follows:

- develop a baseline habitat model to describe habitat selection and resulting caribou distribution in the vicinity of the proposed route of the ITH;
- using the baseline habitat model, assess whether caribou habitat selection has changed in the vicinity of the highway after it was built; and,
- develop a model to estimate the probability of caribou crossing the proposed route of the road and compare this baseline estimate with data collected after the road is built.

METHODS

Caribou Collar Data

Global Positioning System (GPS) collars are regularly deployed on limited numbers of caribou from the Bluenose West, Tuktoyaktuk Peninsula, and Cape Bathurst caribou herds to track their locations and movements. Collars are programmed to transmit a location signal to satellites every four to eight hours during their three years of operation (Davison et al. 2020). Subsets of these collars were additionally programmed with geofencing capabilities; this increases location data transmission frequency to once an hour when the caribou gets within 15 km of the ITH.

Collar locations that were within the vicinity of the road where habitat classification data was available were used in the analysis (Appendix 1). Caribou were primarily to the northeast of the road area during all the years in the analysis (Figure 1), regardless of whether the road was present, suggesting that the road was on the peripheral western flank of seasonal ranges when herd numbers are low (ACCWM 2014).

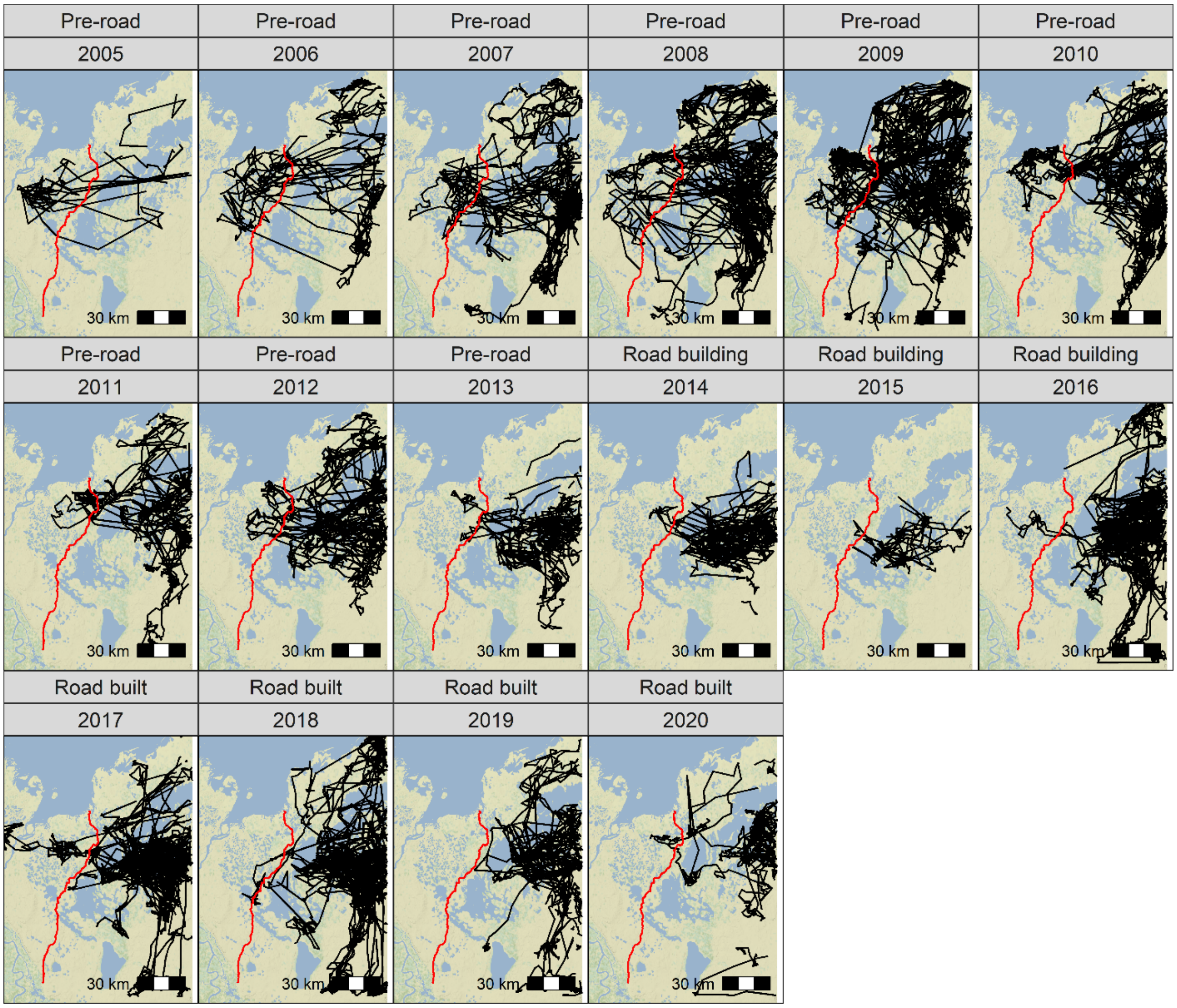


Figure 1. Paths of collared caribou (black) relative to the road (red) each year.

The herds that were present in the vicinity of the road were the Tuktoyaktuk Peninsula and Cape Bathurst herds. The collars indicated that caribou were near the road primarily during the winter, with some occurrences during the spring and fall. Previous analyses (Nagy et al. 2005) also suggested that the seasonal ranges of these herds were closest to the road during the fall and winter. The number of collared caribou that were in close proximity to the road (<2 km) ranged from one to 18 caribou per year. At least twice as many female caribou were collared than male caribou in all years. Appendix 2 provides a full description of collared caribou used in the analysis.

Resource Selection Function Analysis

A resource selection function (RSF) analysis was used to formulate the baseline model for the analysis. In its simplest form, a RSF analysis estimates how a given habitat type would be selected if offered in equal proportion to other habitat types (Manly et al. 1993).

The relative proportion of habitat types in a 500 m buffer radius (the maximum error of the GPS collars) around collar locations was estimated for each caribou location. Each buffered point was compared with the buffered area around five random points that were within a specified distance from the previous location of the collared caribou. This distance was the "availability radius", defined by the 95th percentile of the distance moved by caribou between successive point locations (Arthur et al. 1996, Johnson et al. 2005).

Habitat covariates were standardized by their mean and standard deviation ($x' = [x - std(x)]/\bar{x}$), which expressed each covariate in units of standard deviation. This approach helped accommodate different scales of covariates (e.g. elevation and proportion habitat) and made it possible to compare the coefficients of each covariate in the model (since they were all in units of standard deviation). Tests for significance of the main RSF model covariates were conducted with and without standardized variables to assess if standardization affected overall model results.

Caribou location points (used) and random points were modeled using conditional logistic regression (Hosmer and Lemeshow 2000). The analysis defined each used and five accompanying random points as a cluster. This cluster centered each comparison on the habitat available to the caribou at the time at which the location was recorded. Potential underestimation of parameter variances due to autocorrelation between repeated yearly points of individual caribou was modeled using a generalized estimating equations (GEE) variance estimator (Pendergast et al. 1996, Koper and Manseau 2009).

Because the model is based on used versus random locations, it is not possible to estimate probability of use given that some of the random locations may have been utilized by caribou. For this reason, all estimates were interpreted as odds ratios which is the exponent of each of the slope terms (Manly et al. 1993, Johnson et al. 2006). An odds ratio of 1 would imply that the given habitat is not selected. If the odds ratio was <1, then the habitat was avoided, whereas an odds ratio of >1 would imply that the habitat is selected.

The resource selection function analysis is described in detail in the Appendix 3.

Application of Baseline Model to Assess Road Impacts

Once the base models were validated, the next step in the analysis was modeling habitat selection relative to the road. The main question of interest was whether selection changed relative to the road once it was in place. To test and estimate any change, the distance of used and random locations from the road was estimated for several years before as well as after the road was in place. It is noteworthy, however, that the road was only partially built from early 2014 to April 2016, and then once the foundation was completed it was not open to traffic until November 2017 (Figure 2).

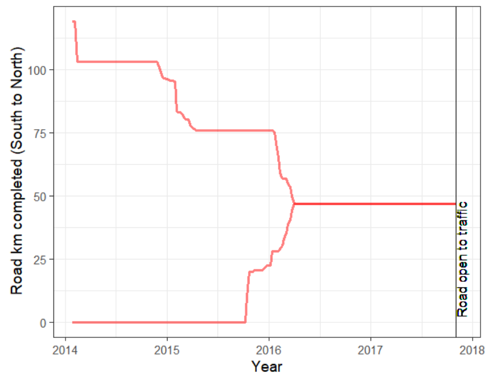


Figure 2. Road construction timeline as indicated by distances where the road construction was completed. The road was opened to traffic in November of 2017.

The selection of caribou at successive 2 km bins from the road was then tested for years prior to building the road (2005-2014), during the construction of the road (2014-2016), and after the road was built. For years prior to the road, the road path was used. Using this approach, the period prior to building the road was a "control" to assess if there were any gradients relative to the route of the road that existed prior to road construction which would then be contrasted with selection after the road was built. The binned interval approach, which has been used in zone of influence studies (Plante et al. 2018, Johnson et al. 2020, Boulanger et al. 2021b), was a more flexible approach to compare variation in selection relative to the road between time periods compared to segmented regression and was therefore used for analyses.

Analyses of post-road data in the more recent analysis was conducted in the R statistical package (R Development Core Team 2009) with GIS analyses conducted using the simple features (*sf*) (Pebesma 2018), *ggplot* (Kahle and Wickham 2013), *ggmap* (Kahle and Wickham 2013) and *raster* packages as well as the QGIS software program (QGIS Foundation 2020). Development of the initial baseline RSF model was conducted using SAS statistical software (SAS Institute 2000).

Road Crossing Analysis

Another key objective of this analysis is to assess whether the road inhibits caribou crossing. This assessment required the creation of a model that estimates the probability of crossing and factors influencing crossing. This model was applied before and after the road was constructed using a Before-After Control-Impact (BACI) type design (Underwood 1990) to assess if presence of the road has influenced the probability of caribou crossing the road.

Crossing was defined as when sequential individual caribou locations occurred on different sides of the proposed route of the road. Logistic regression was used to estimate the probability of caribou crossing the proposed road location. The main factors considered were the proximity of individual caribou to the road (as determined by distance from the road of daily locations), herd, sex of caribou, season and phase of road development. From this, the probability of caribou crossing the road was estimated. Fix intervals from daily to four hours were used in the analysis. The effect of fix interval was tested using a fix interval covariate in the analysis.

As with the RSF analysis, the model used involved repeated observations of individual caribou. For this analysis, a mixed effects logistic regression model (Hosmer and Lemeshow 2000, Milliken and Johnson 2002, Koper and Manseau 2009) was used with the probability of a caribou crossing the road (intercept of the analysis) and the slope of distance from road and probability of crossing the road was modeled as a random effect, therefore allowing a unique slope/intercept for each caribou in the analysis. The main terms to be tested were then modeled as fixed effects to assess overall population level effects of each covariate.

RESULTS

Resource Selection Function Analysis

Baseline RSF Model

The study area was dominated by dwarf shrub, water, wet graminoid, and woodland needle leaf habitat types (Appendix 1). In many habitat types, the proportion of used habitat types versus random availability of habitat types was different suggesting habitat selection (as tested in the RSF model exercise in Appendix 3). Seasonal selection was considered using an interaction of habitat type and month.

The base model was developed using data up to 2013 which involved univariate testing of each covariate followed by the building of a multivariate base model. For the sake of brevity this analysis is detailed in Appendix 3. The base model was then applied to the more recent data set that included 2014-2020 location data (when the road was being built or operating). Model parameters from the original base model were significant when the newer data set was applied (Table 1).

Table 1. RSF habitat model for caribou habitat selection within 70 kilometers of the ITH. Standardized logit-scale parameters are given along with standard errors (SE), Z tests, and p-value of the Z-test (p(Z)).

Parameter	Category	DF	Estimate	SE	Z	P(Z)
Aspect	SW	1	0.304	0.029	10.627	<0.0001
	NE	1	0.302	0.030	9.933	<0.0001
	NW	1	0.339	0.028	12.247	<0.0001
	SE	1	0.300	0.027	11.293	<0.0001
$Barren^2$		1	-0.008	0.003	-3.051	0.0023
Barren*herd	CB	1	0.065	0.025	2.637	0.0084
Closed tall $shrub^2$		1	-0.050	0.007	-7.337	<0.0001
$Elevation^2$		1	-0.049	0.015	-3.382	0.0007
Dwarf shrub		1	0.063	0.037	1.722	0.0851
Dwarf shrub*herd	CB	1	0.209	0.040	5.174	<0.0001
Low shrub		1	0.059	0.026	2.329	0.0199
Low $shrub^2$		1	-0.027	-0.027	-4.045	0.0001
Open deciduous		1	-0.131	-0.132	-8.042	<0.0001
Open $spruce^2$		1	-0.010	0.016	-2.438	0.0000
$Slope^2$		1	-0.012	0.004	-4.576	<0.0001
Water		1	-0.689	0.003	-9.072	<0.0001
$Water^2$		1	-0.355	0.076	-19.142	<0.0001
Water*month		1	0.081	0.019	7.217	<0.0001

The model was cross validated with observed (using model testing data) and expected frequencies (using training data) of locations being compared for each year and month of the analysis. Correlation between observed and expected in binned interval was significant in all years, with median correlations above 0.9 for all years.

A plot of spatial prediction of the base model reveals areas of higher selection surrounding many of the larger lake features with lower selection in far southeastern and southwestern portions (Figure 3).

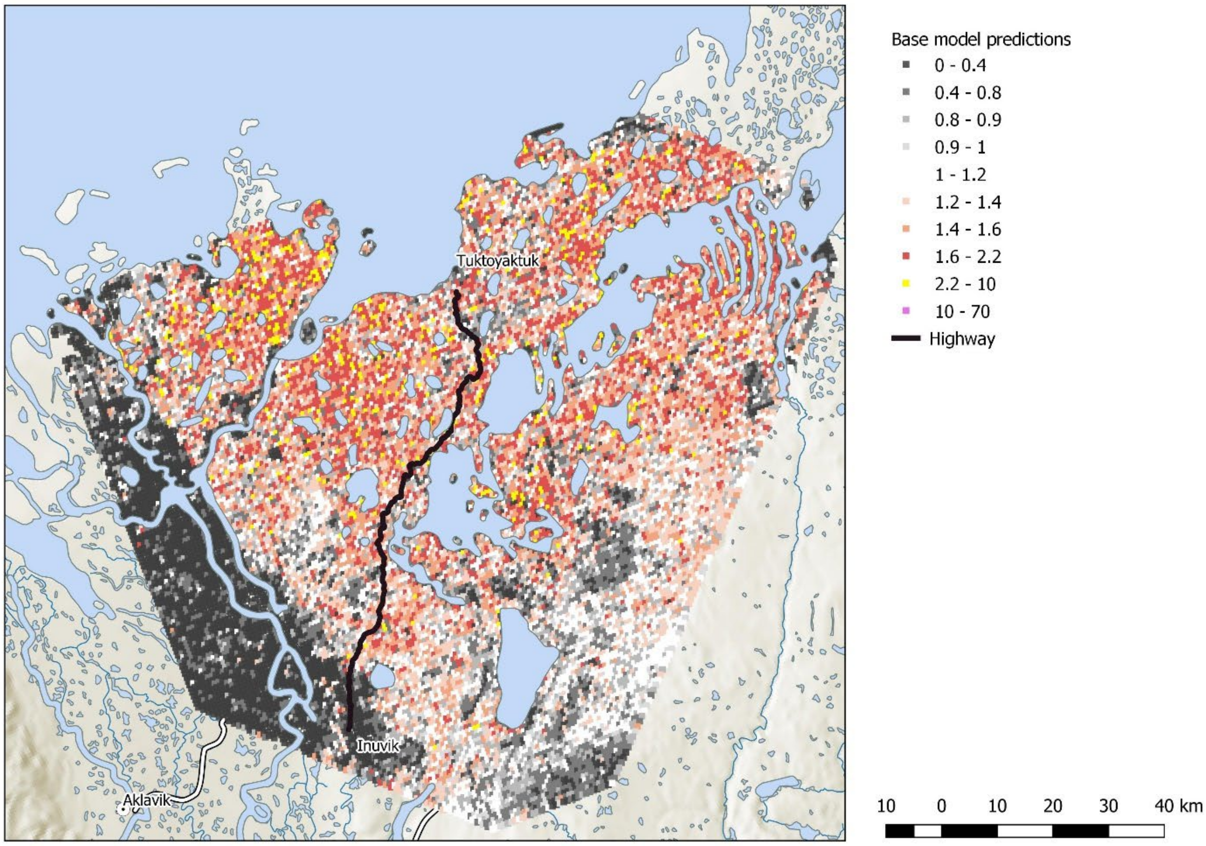


Figure 3. Predicted selection of caribou from the base model (Table 1).

Impacts of the Road on Habitat Selection

The next step in the analysis was modeling habitat selection relative to the road by considering selection at binned interval distances from the road. The distribution of caribou and subsequent number of points relative to the road by phase was limiting, especially to the west of the road (Figure 4) with relatively few locations after 15-20 km west of the road. For this reason, 2 km intervals were used up to 10 km, followed by a 10-15 km interval and distances greater than 15 km pooled into a single category.

Figure 4 shows random and used locations to provide an initial test of whether there were gradients in habitat selection relative to the road which would be indicated by bars where the relative proportion of random points was greater than used points if habitat selection was negative and vice-versa if positive. This is a preliminary comparison given that the effect of difference in habitats relative the road is not being considered.

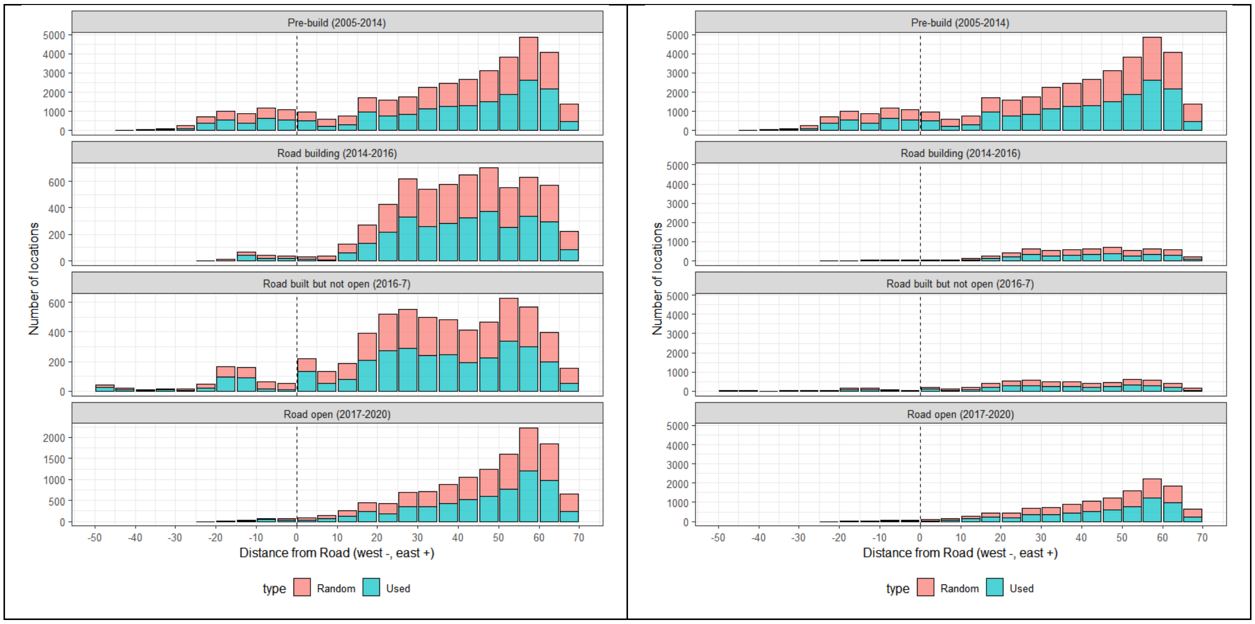


Figure 4. Frequencies of used and random locations relative to the road by period of construction up to 20 km. Note the different scales for the y-axis on the left figure. The right figure shows the same data with similar y-scales.

Base models that were run with all build phases did not converge, which was due to low sample sizes during the build period. Especially challenging was the road building phase when the road was only partially built and therefore caribou were only partially exposed to the road. To offset this issue, we removed data from the road building phase from the analysis and pooled phases into a pre-road (2006-2014) and a road-built phase (2016-2020). This strategy ensured caribou had equal exposure to the road for the resulting road-built phase. The road was not open to traffic until 2017, however, during this time there was construction traffic on the road and therefore it was reasonable to pool the "road built but not open" and "road open" phases.

The significance of binned interval terms was then evaluated by period of road construction. The easiest way to assess results is plotting odds ratio scores for binned intervals (Figure 5), standardized for all other habitat variables at mean levels. This plot shows that the confidence limits on odds ratios all overlapped 1 (suggesting no selection) for the "prior to full road construction" period. In the post-road period, odds ratios were significantly <1 up to 10 km west of the road and 2 km east of the road. A gradient in selection to the east of the road was suggested up to 8 km; however, only the 0-2 km bins up to 6 km were significant. This result suggests that selection was diminished from 10 km west to approximately 2 km east of the road.

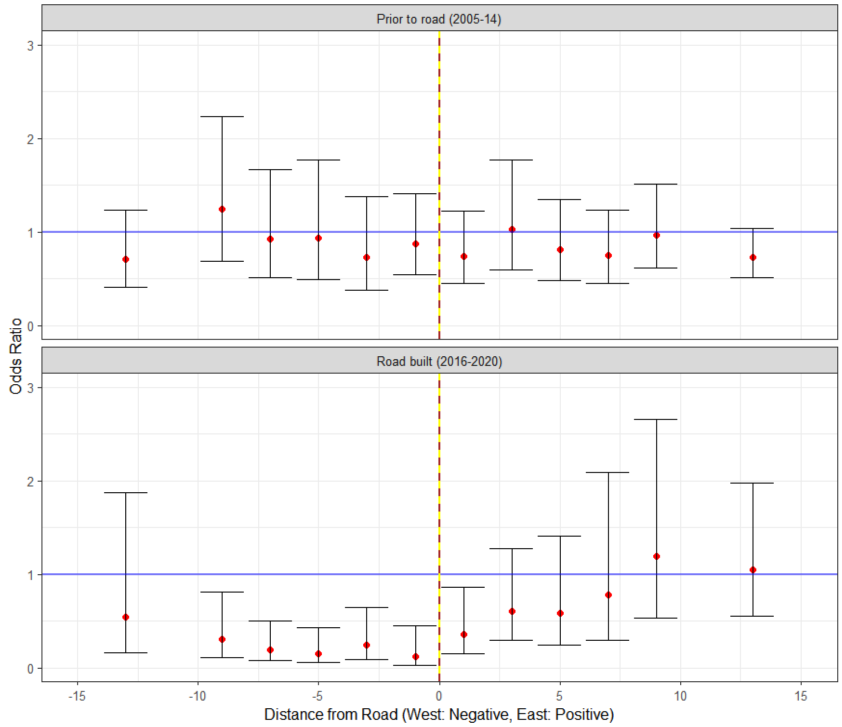
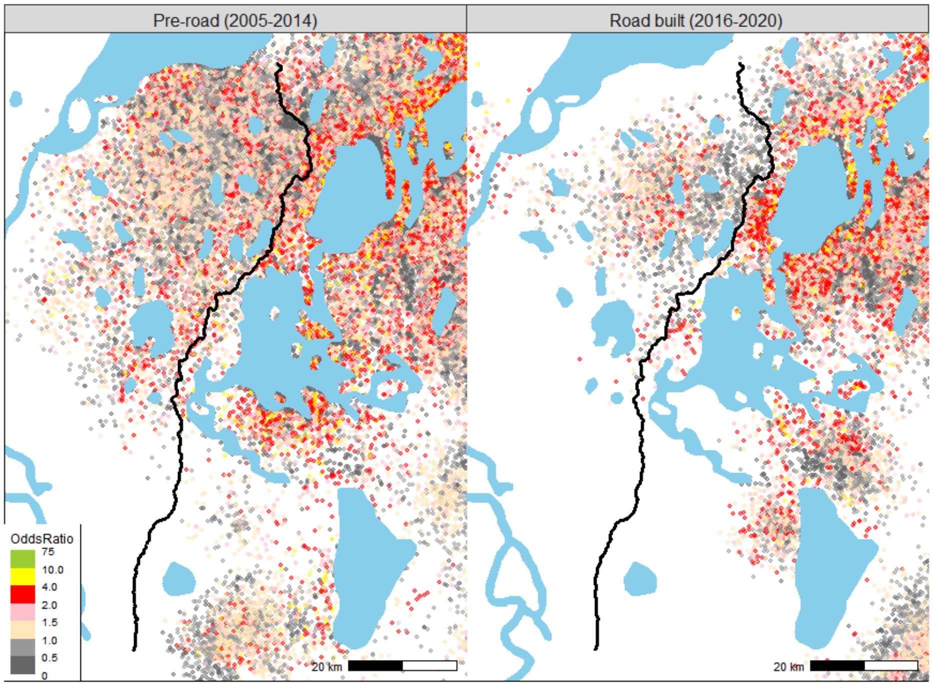


Figure 5. Odds ratios for selection relative to binned distance from road intervals. The midpoint of each bin interval is shown with confidence limits on model predictions. Significant intervals are indicated by when the confidence limit does not cross the odds ratio = 1 line.

Models were run that added more binned intervals to the west of the road. In general, habitat selection was lower for both pre- and post-road periods in this area, presumably due to this area being in the southwestern extent of seasonal ranges.

A plot of spatial predictions from the binned interval model in Figure 5 shows an area of lower selection to the west and immediately east of the road arising during the road-open phase of the analysis (Figure 6). Only the northern half of the road impacted caribou, given that their range prior to the road did not extend to the southern half of the road.

Predicted selection relative to road



Predictions with used locations in blue

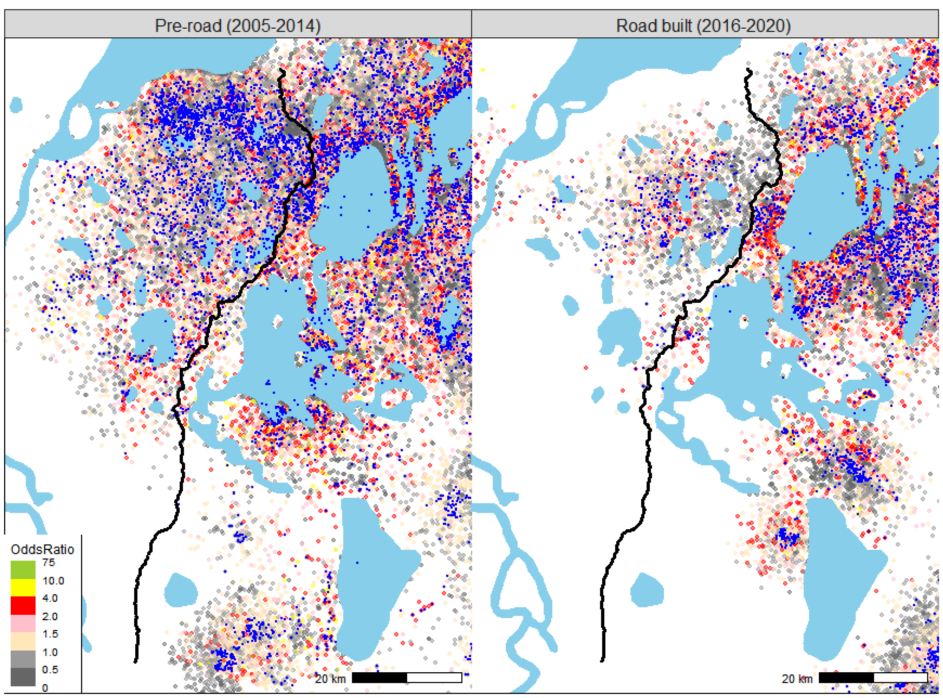


Figure 6. Spatial predictions of binned interval model (Figure 5) by road phase. The lower plot also displays the used collar locations in blue.

Road Crossing Analysis

Seventy-two, six and 22 collared caribou came within 10 km of the road during the pre-road, road building, and post-road time periods (Table 2). Of these, 82% (59 of 72), 33% (two of six), and 27% (six of 22) of these caribou crossed the road from the east to west side during each of the three road phases. Most caribou initially encountered the road in the fall and were often in the vicinity of the road throughout the winter. Most collared caribou were female with only 20 males in the entire data set.

Table 2. Summary statistics for road crossing analysis. Caribou that came within 10 km of the road were considered in the analysis. The initial season is indicated, however in some cases caribou were within the road area for more than one season. The column "collars that crossed at least once" indicates the number of collared caribou that crossed the road at least one time. Total crossing events included records for caribou that crossed the road more than once in a given year.

Phase	Collars			Initial season			Crossings	
	Total	Female	Male	Fall	Winter	Spring migration	Collars crossed at least once	Total crossing events
Pre-road	72	57	15	43	29	0	59	237
Build	6	6	0	2	4	0	2	10
Post-road	22	17	5	12	7	3	6	19

The logistic model was then used to determine factors associated with road crossing. Caribou herd, the slope of the distance from road, and crossing probability were modeled as random effects. Distance from the road was assessed when the road was present and not present as a control factor. This was modeled using a phase term (pre-road, build, and post-road) and a pooled phase term (pre-road and road).

Logistic Mixed Model Regression Analysis

Model selection results from the analysis suggested that the most supported model included road phase (pooled into pre-road and road), distance from road (d), and interactions of side of road and distance from road (d), and phase and side of road (Table 3). More complex models, and models that included build as a phase did not converge. Model selection results should be interpreted cautiously given that the AIC statistic only considers fixed effect parameters and not the random effect slope parameters. This issue was offset partially by including the same random effect configuration in all models and therefore the only difference between models was formulation in fixed effects.

Table 3. Logistic mixed model selection results for road crossing analysis. The sample size corrected Akaike-Information criterion (AIC_c), the difference between the most supported and given model (ΔAIC_c), the weight of support (W_i), the number of parameters in the model (K), and log-likelihood are given. Model symbology is as follows (d: distance from road; ld: log distance from road; interval: fix interval; side: side of road; Phase: road phase - pre, build, and road; PhaseP: pre-full road, road; Phase3: pre-road, road-build, road open).

No	Model	AIC_c	ΔAIC_c	w_i	K	LL
1	PhaseP+d+side*d+PhaseP*side	1549.5	0.00	0.84	8	-766.7
2	PhaseP+d+side*d	1554.9	5.42	0.06	7	-770.5
3	PhaseP+d+side*d +sex*d	1556.0	6.52	0.03	8	-770.0
4	PhaseP+d+side*d+d*interval	1556.9	7.38	0.02	8	-770.4
5	PhaseP+d+side*d+PhaseP*d	1556.9	7.41	0.02	8	-770.4
6	Phase+d+side*d	1557.3	7.76	0.02	8	-770.6
7	PhaseP+d	1560.1	10.58	0.00	6	-774.0
8	PhaseP+d+RoadPhaseP*d	1562.0	12.50	0.00	7	-774.0
9	PhaseP+d+side	1562.0	12.52	0.00	7	-774.0
10	PhaseP+d+herd+season	1572.2	22.65	0.00	9	-777.1
11	D	1577.2	27.67	0.00	5	-783.6
12	PhaseP+ld+side	1577.7	28.22	0.00	6	-782.9
13	PhaseP+d+herd+side	1577.7	28.22	0.00	6	-782.9
14	Phase+ld+side	1601.6	52.13	0.00	7	-793.8

Parameter estimates from the most supported model were all significant (Table 4). The road phase term suggested that the probability of crossing the road was lower after the road was built. In terms of odds ratios (the exponent of the road phase term), a caribou was 0.13 times less likely to cross when the road was in place. Results also suggested that caribou were more likely to cross west to east than east to west when the road was in place.

Table 4. Model parameter estimates from the most supported Logistic model (Table 3, model 1).

Parameter	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-0.508	0.161	-3.160	0.0016
Road Phase (Road)	-2.035	0.427	-4.767	0.0000
Distance from road	-0.364	0.041	-8.887	0.0000
Distance from road*side (west)	-0.098	0.032	-3.103	0.0019
Road Phase*side (west)	1.493	0.544	2.747	0.0060

A plot of predictions from the most supported model illustrates reduced crossing probabilities when the road was in place (Figure 7). The spread of points is based upon slopes for individual caribou relative to the road as estimated by the random effects term.

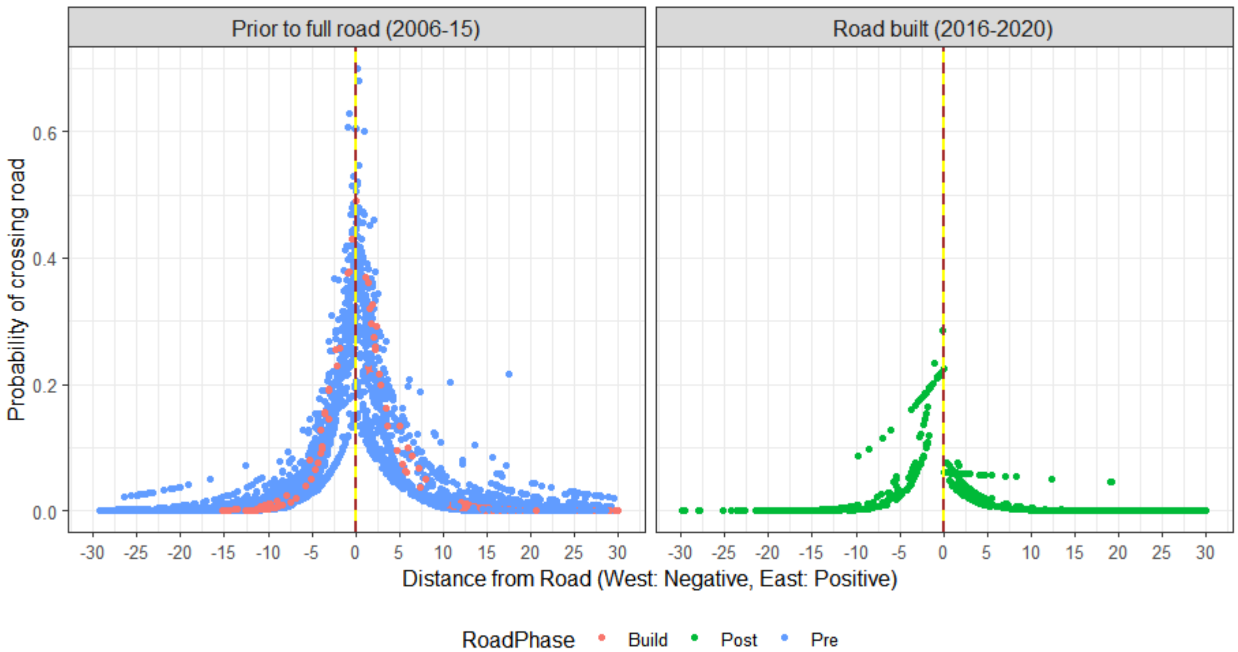


Figure 7. Predicted probabilities of crossing to the west and east of the road from the most supported logistic model.

A plot of individual tracks of caribou after the road was built provides further insight into the response to the road (Figure 8). Many (at least seven caribou) approach the road from the east and then have clusters of locations within the proximity of the road before crossing (or not crossing). One male was in the immediate vicinity of the road (BGCA 18220) from spring migration to post calving. Limited sample sizes (five males total) precluded investigation of sex-specific behavior towards the road; however, the behavior of this caribou was not typical of other caribou shown in Figure 8.

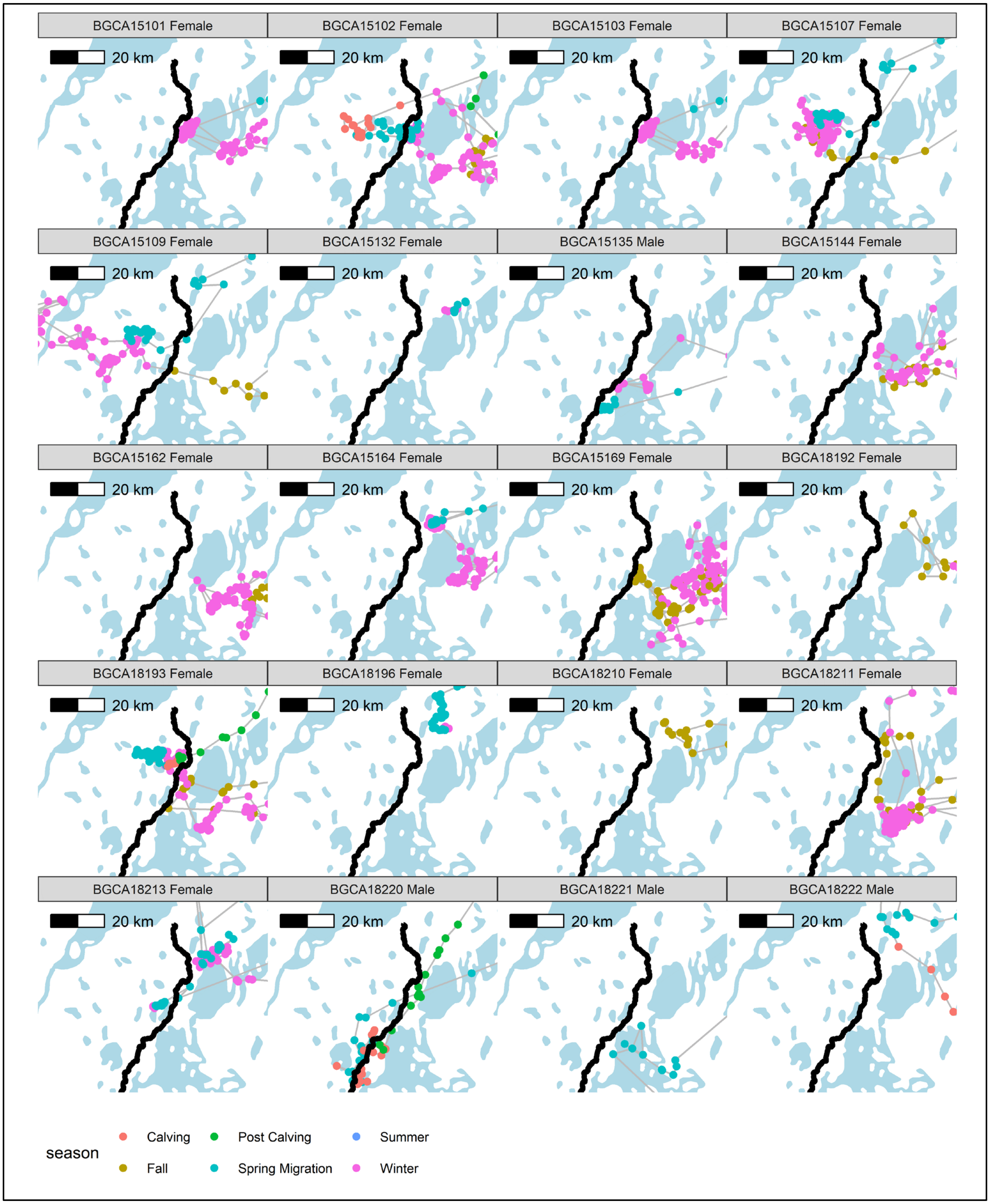


Figure 8. Paths of caribou in the proximity of the road (within 10 km) for 2017-2020 (when the road had been fully built).

The spatial-temporal aspect of paths relative to the road can also be viewed by individual caribou using movement trajectory plots (Figure 9). These illustrate the amount of time spent in proximity to the road and caribou movement during that time. Also shown in the plot is the 10 km west to 2 km east zone where habitat selection was reduced. Many caribou (at least nine) come within the proximity of the road (5 km) but do not cross. One caribou (BGCA15107) crosses the road then stays 10 km west of the road before quickly crossing back to the east. However, one male (BGCA18220) is in the proximity of the road from May to July illustrating that there is variation in caribou response to the road.

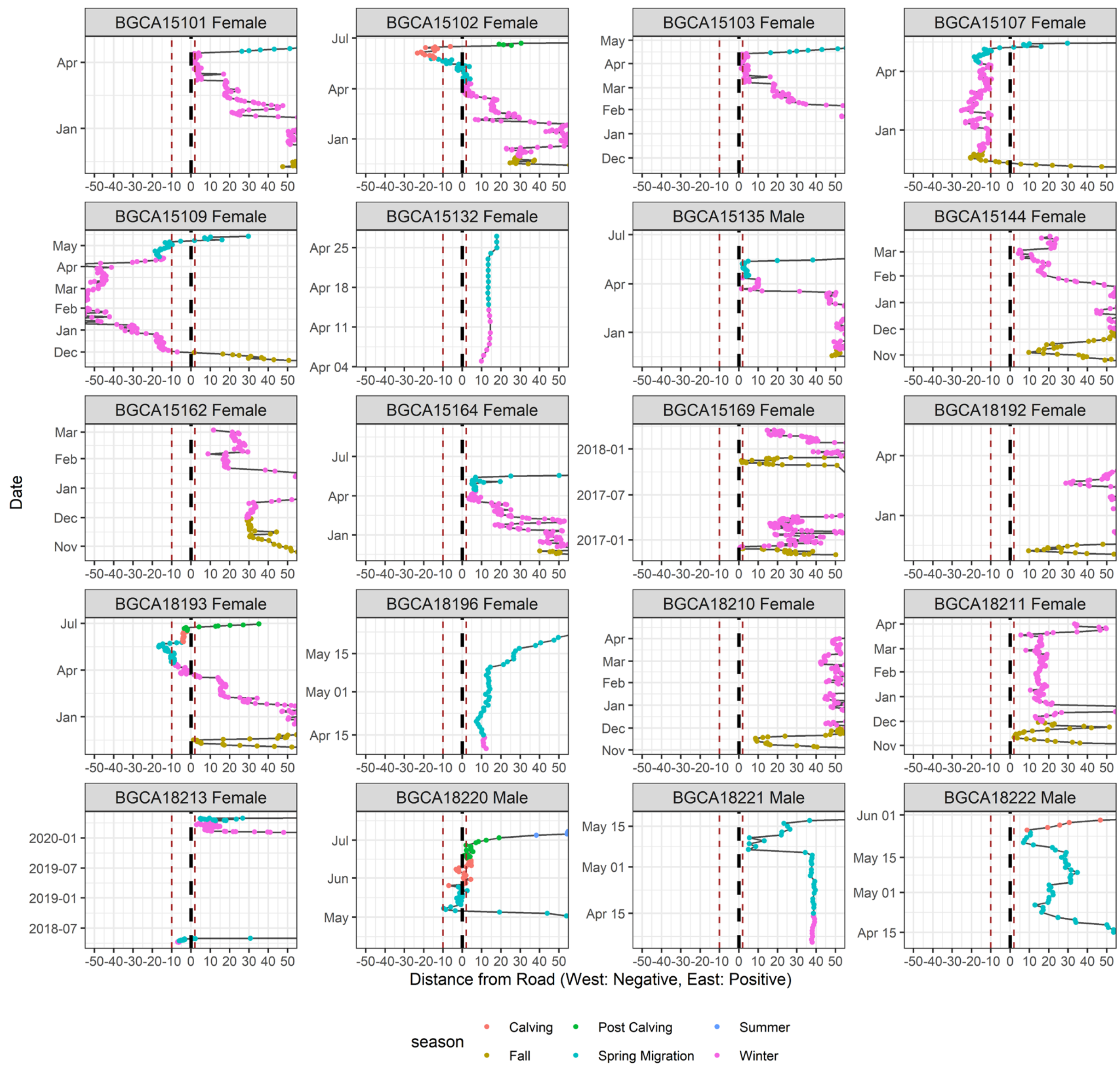


Figure 9. Movement trajectory plots for caribou that were in the vicinity of the road after it was built. The paths of the same caribou are shown in Figure 8. The zone of the road (10 km west to 2 km east) that was estimated to have lower selection due to the road by the RSF analysis (Figure 6) is shown for reference. Note the different date scales on the y-axis.

Traffic volume was available for a subset of dates after the road was built. Sample sizes were not sufficient for statistical analyses; however, this data set could be useful when more data is available. Figure 10 shows example movement trajectories for caribou in the vicinity of the road with relative traffic volume displayed via color ramps at distance from road equal to 0. For caribou BGCA 18220, much of the time period when it was crossing the road traffic volume was at or near zero.

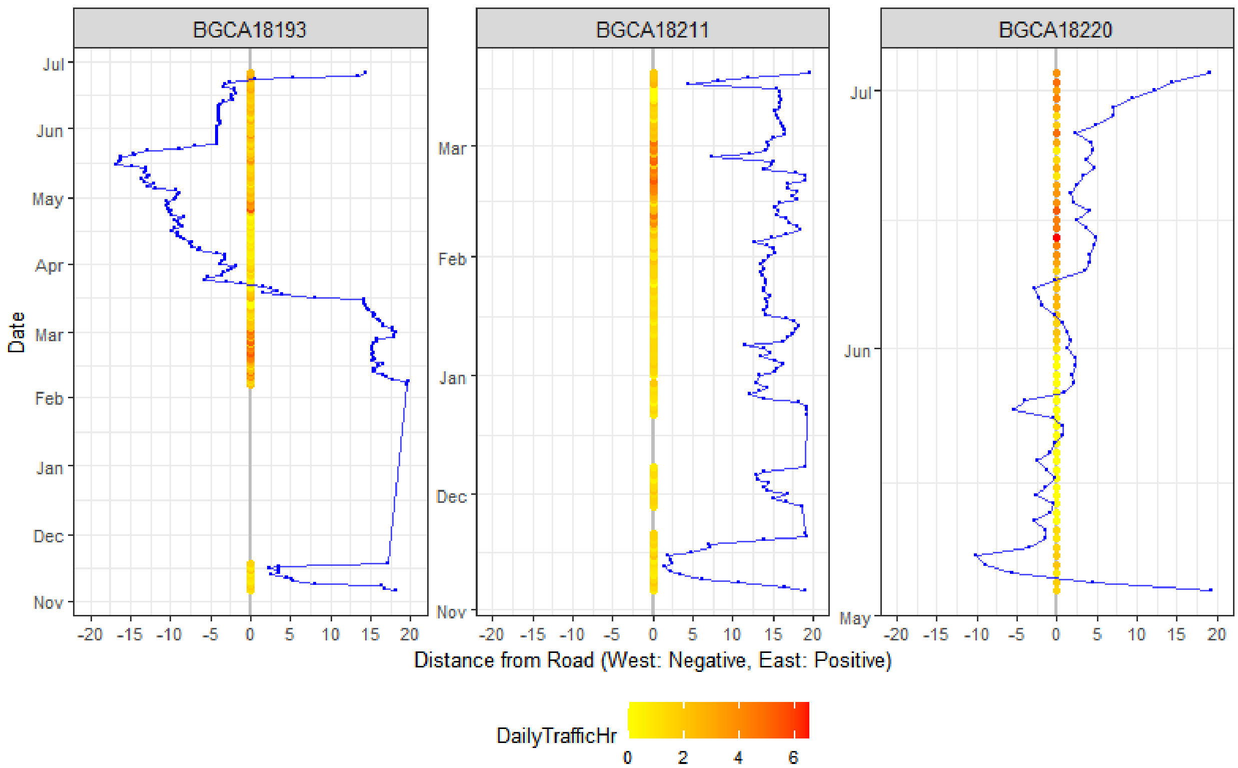


Figure 10. Movement trajectory plots for caribou that were in the vicinity of the road after it was built. The mean traffic per hours (summarized daily) is presented along the distance from road = 0 vertical axis.

DISCUSSION

The results of this analysis suggest that the ITH influences caribou on the southwest edge of their distribution, with reduced selection of the west side of the highway (Figures 4-6). This result is based upon a comparison of habitat selection in areas adjacent to the highway prior to and after completion and opening of the highway. The likely mechanism for this reduction of selection/distribution is a reduced probability of crossing the road area which results in lowered use and selection of the areas west of the highway (Figure 7).

The finding that selection is reduced to the west of the highway could potentially be due to caribou moving away from the highway after crossing initially from the east. Other studies (Panzacchi et al. 2013, Wilson et al. 2016, Boulanger et al. 2021a) have found that caribou often move away from the road after crossing which could potentially contribute to lower habitat selection to the west of the road. The movement trajectory plots illustrate this type of behaviour for some of the collared caribou (Figure 9).

One of the main differences between this analysis and other analyses of the impact of roads on caribou (Wilson et al. 2016, Kite et al. 2017, Boulanger et al. 2021a) is that the road does not bisect a migration corridor but instead encompasses part of the seasonal winter range of the caribou. Therefore, metrics such a bias correlated random walk, or mine offset rate, which assumes directional movement do not readily apply to the analysis. Instead, the main question boils down to whether the road excludes the caribou from the western extent of their seasonal range. This type of question was best considered in the context of a habitat selection analysis. A binned selection analysis (Plante et al. 2018, Johnson et al. 2020) was most applicable in this case since it allowed matching of distance from road for pre- and post-development phases. Piecewise regression (Boulanger et al. 2021b), which estimates a zone of influence, could have also been used; however, this approach is not as easily constrained to assess interactions as the binned interval approach.

One of the limitations of these analyses is the relatively low number of collared caribou that occurred near the road after the road was built. This limited the ability of the analyses to assess season-, sex-, or herd-specific trends in road crossings and habitat selection near the road.

Unfortunately, the caribou herds in the area during the timeframe of this analysis were at historic low levels and the range was contracted compared to the early 1990s when the herds were at a peak (Nagy and Johnson 2013, Davison et al. 2017, Boulanger et al. 2018). During the time of the Inuvialuit Harvest Study (1988-1997) there were significant numbers of caribou being harvested by Tuktoyaktuk and Inuvik hunters (annual mean 915 and 579 respectively)(Joint Secretariat 2003). Therefore, it is likely that the range depicted by pre-road collar data may not indicate the full historic range of caribou relative to the road. If the herd numbers increase, and range expands, there may be more caribou in proximity to and crossing the ITH. It would be beneficial for this analysis to be repeated as more data from collared caribou becomes available.

Potential Future Analyses

The main objective of the analysis was to present an initial assessment of potential impacts of the road rather than to address potential mitigation strategies. One potentially useful analysis would be to assess areas where caribou are crossing the road in terms of finer scale covariates such as road berm height, snowbank heights, as well as traffic volumes on the highway relative to crossing events. These covariates could be added to the logistic regression crossing model to provide assessments of potential mitigation strategies. A preliminary traffic volume analysis was conducted, however, there were too few crossings during periods where traffic volume counters were operational. In the future this analysis could be pursued as traffic volume and road crossing data accumulates. Finally, it is possible to add habitat covariates to better predict actual areas that the road is most likely to be crossed. This approach has been used to identify crossing locations of grizzly bears in Alberta (Graham et al. 2010). A GIS exercise that interpolates the path of caribou could assist in estimating actual road crossing locations.

ACKNOWLEDGEMENTS

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APPENDICES

This appendix details the development of RSF analyses as well as providing in-depth summaries of sample sizes of collared caribou used in the analysis.

Appendix 1. Habitat Covariates used in the Analysis

Habitat covariates were defined from the Ducks Unlimited remote sensing habitat classification project (Environment and Natural Resources (ENR), Inuvik, unpublished draft report, (Edwards 2009). The actual habitat types were extracted from hierarchical habitat categories based upon the dominant classifications detected within the survey area (Figure 11).

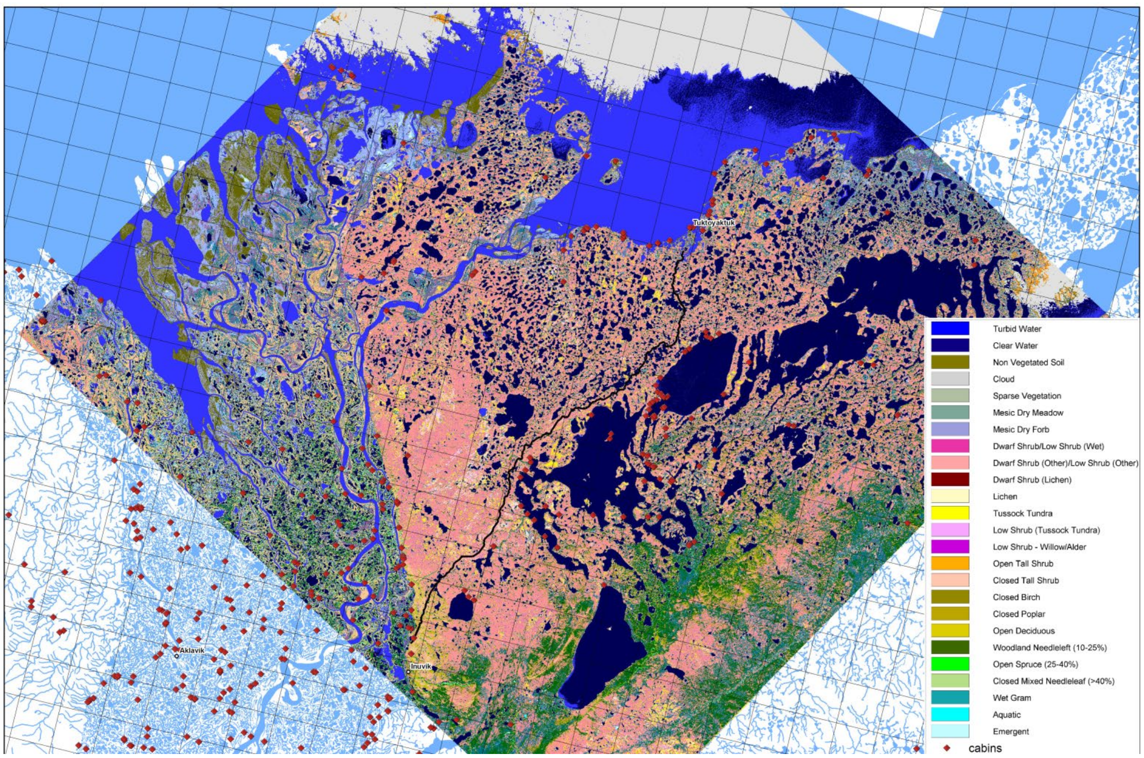

Figure 11. The study area considered in this analysis as defined by remote sensing habitat categories. The proposed road can be seen in black in the central part of the study area.

Habitat categories were based on remote sensing data as shown in Table 5.

Table 5. Correspondence of habitat classes used in analysis as listed in ENR (unpublished). Habitats in green were present in the study area and were used in the analysis.

Level II	Level III	Level IV	Level V
1.0 Forest	1.1 Closed Needleleaf (NL)	1.11 Closed Spruce	
		1.12 Closed Pine	
		1.13 Closed Tamarack	
		1.14 Closed Fir	
		1.13 Closed Mixed Needleleaf	
	1.2 Open Needleleaf	1.21 Open Spruce	1.211 Open Spruce / Lichen
			1.212 Open Spruce / Moss
			1.213 Open Spruce / Other
		1.22 Open Pine	1.221 Open Pine / Lichen
			1.222 Open Pine / Moss
			1.223 Open Pine / Other
		1.23 Open Tamarack	1.231 Open Tamarack / Lichen
			1.232 Open Tamarack / Moss
			1.233 Open Tamarack / Wet Graminoid
			1.234 Open Tamarack / Other
		1.24 Open Fir	1.2.41 Open Fir / Lichen
			1.2.42 Open Fir / Moss
			1.2.43 Open Fir / Other
		1.25 Open Mixed Needleleaf	1.251 Open Mixed Needleleaf / Lichen
			1.252 Open Mixed Needleleaf / Moss
			1.253 Open Mixed Needleleaf / Other
	1.3 Woodland Needleleaf	1.31 Woodland Needleleaf / Lichen	
		1.32 Woodland Needleleaf / Moss	
		1.33 Woodland Needleleaf / Other	
	1.4 Closed Deciduous	1.41 Closed White Birch	
		1.42 Closed Aspen	
		1.43 Closed Poplar	
		1.44 Closed Mixed Deciduous	
	1.5 Open Deciduous	1.51 Open White Birch	
		1.52 Open Aspen	
		1.53 Open Poplar	
		1.54 Open Mixed Deciduous	
	1.6 Closed Mixed NL/Deciduous		
	1.7 Open Mixed NL/Deciduo	1.71 Open Mixed NL/Deciduous Lichen	
		1.72 Open Mixed NL/Deciduous Moss	
		1.73 Open Mixed NL/Deciduous Other	
2.0 Shrub	2.1 Tall Shrub	2.11 Closed Tall Shrub	
		2.12 Open Tall Shrub	2.121 Open Tall Shrub / Lichen
			2.122 Open Tall Shrub / Moss
			2.123 Open Tall Shrub / Other
	2.2 Low Shrub	2.21 Low Shrub / Tussock Tundra	
		2.22 Low Shrub / Lichen	
		2.23 Low Shrub / Moss	
		2.24 Low Shrub / Willow-Alder	
		2.25 Low Shrub / Herbaceous	
		2.26 Low Shrub / Other	
	2.3 Dwarf Shrub	2.31 Dwarf Shrub / Lichen	
		2.32 Dwarf Shrub / Other	
3.0 Herbaceous	3.1 Bryoid	3.11 Lichen	
		3.12 Moss	
	3.2 Wet Herbaceous	3.21Wet Graminoid	
		3.22 Wet Forb	
	3.3 Mesic/Dry Herbaceous	3.31 Mesic/Dry Graminoid	
		3.32 Mesic/Dry Forb	
		3.33 Tussock Tundra / Other	
		3.34 Tussock Tundra / Lichen	
4.0 Aquatic Veg.	4.1 Aquatic Bed		
	4.2 Emergent Vegetation		
5.0 Water	5.1 Snow		
	5.2 Ice		
	5.3 Clear Water		
	5.4 Turbid Water		
6.0 Barren			
	6.1 Sparsely Vegetated		
	6.2 Rock/Gravel		
	6.3 Non-Veg. Soil		
	6.4 Recent Burn		
7.0 Urban			
8.0 Agriculture			
9.0 Cloud/Shadow	9.1 Cloud		
	9.2 Shadow		
10.0 Other			

The primary period considered for the habitat model was fall, winter, and spring migration and therefore it could be argued that some of the vegetation classes such as emergent vegetation and water may be less applicable since the ground was frozen or covered in ice and snow. The basic approach used to confront this was to test each category for significance rather than subjectively eliminate categories. The assumption in this case is that each of the habitat classes may be an indicator of micro-climate or habitat attributes during the winter season. If a habitat category was irrelevant, then the RSF analysis would not indicate significant habitat selection and the covariate was dropped from the RSF model.

Principal Components Analysis to Optimize Modeling of Habitats

The proportions of habitat classes are likely correlated given the similarity of land cover and associations among different vegetative types. To determine the most parsimonious combinations of covariates that describe caribou habitat selection, we assessed the structural relationships between habitat covariates. Principal components analysis was used to discern this structural relationship to allow further interpretation of the RSF habitat model results (Tabachnick and Fidell 1996, McGarigal et al. 2000).

Structural relationships between habitat covariates were assessed using correlation analysis and principal components analysis. None of the habitat categories displayed a correlation coefficient greater than 0.5 except for dwarf shrub and water which had a Pearson correlation coefficient of -0.86, suggesting that these two categories were negatively associated.

Principal components analysis resulted in three factors that summarized 49% of the variation in the data set. As with the correlation analysis, water and dwarf shrub were negatively related on the first component axis, with positive associations of dwarf shrub with open deciduous, woodland (needle leaf), and elevation. For the second factor, mesic dry and low shrub were positively associated (Table 6).

Table 6. Standardized coefficients from principal components analysis. Significant loadings are shown in bold.

Variable	Factor1	Factor2	Factor3
Water	**-0.86**	-0.46	0.06
Barren	0.03	0.18	0.49
Mesic dry	0.06	**0.84**	0.16
Dwarf shrub	**0.73**	0.32	-0.41
Lichen	0.01	0.46	0.26
Low shrub	0.19	**0.67**	-0.42
Open tall shrub	-0.05	0.38	0.54
Closed tall shrub	0.53	-0.31	-0.15
Closed deciduous	0.33	-0.33	0.15
Open deciduous	**0.68**	-0.41	0.06
Woodland	**0.66**	-0.21	0.33
Open spruce	0.39	-0.34	0.18
Closed needleleaf	0.37	-0.33	0.37
Wet graminoid	0.35	0.47	0.34
Elevation	**0.68**	0.00	-0.10
Slope	0.49	-0.06	-0.08

A component plot also demonstrates the negative association of water with the woodland categories, as well as open categories such as low shrub and mesic dry (Figure 12).

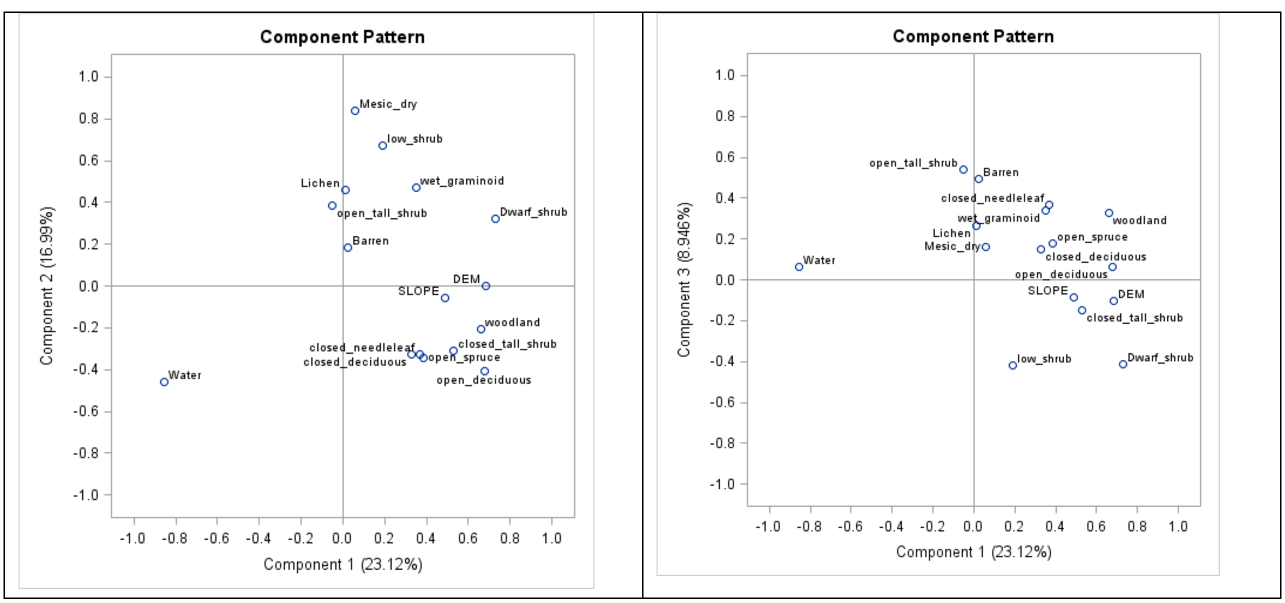

Figure 12. Relationship of principal component factors for terms listed in Table 6.

Appendix 2. Summary of Caribou Collar Data used in the Analysis

Collared caribou data from the Bluenose-West, Tuktoyaktuk Peninsula and Cape Bathurst caribou herds were summarized relative to the area of the proposed road as a function of season (Nagy et al. 2005) as listed in Table 7. Collar locations that were within the area where habitat classification data was available (Figure 11) were used in the analysis.

Table 7. Seasons defined by Nagy et al (2005) used in the collar analysis.

Season	Dates
Calving/post calving	1 - 25 June
Early summer	26 June -15 July
Mid-summer	16 July - 7 August
Late summer	8 August - 7 October
Fall/rut	8 - 31 October
Fall/post rut	1 - 30 November
Winter	1 December - 31 March
Spring, spring migration, and pre-calving	1 April - 31 May

The majority of locations near the road occurred in the winter season with some locations also occurring in the spring migration or fall season (Figure 13). The analysis of Nagy et al (2005) also suggested that the seasonal ranges of these herds were closest to the road during the fall and wintertime periods.

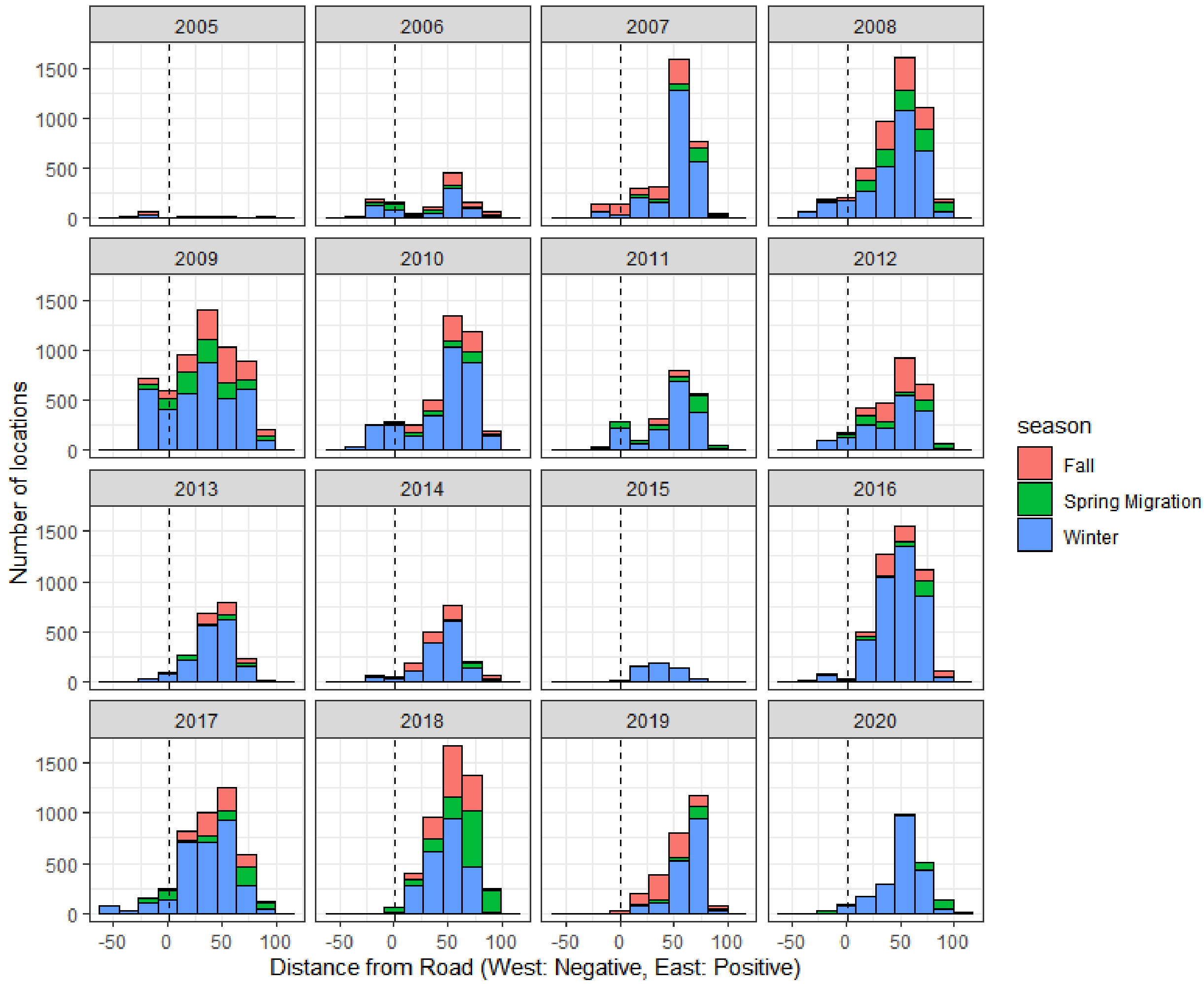

Figure 13. Proportions of points as a function of distance (km) from proposed ITH as a function of season and year. Animal locations were reduced to daily intervals to avoid potential bias in distributions due to geofencing in the proximity of the road.

The main herds that bisected the road were the Tuktoyaktuk and Cape Bathurst herds (Figure 14).

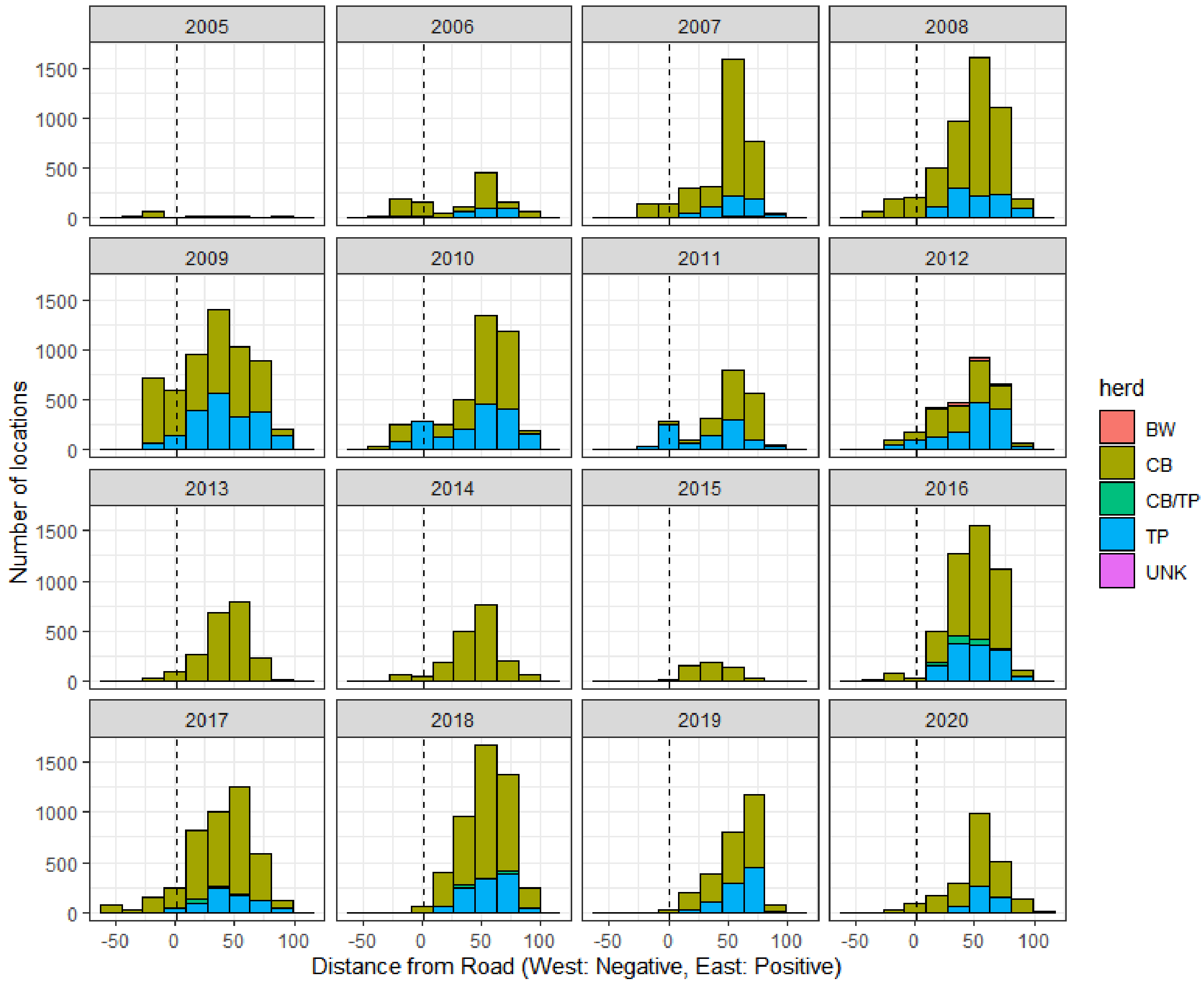

Figure 14. Proportions of points as a function of distance (km) from proposed ITH for the Cape Bathurst (CB) and Tuktoyaktuk Peninsula (TP) herds. Animal locations were reduced to daily intervals to avoid potential bias in distributions due to geofencing in the proximity of the road.

Annual sample sizes of collared caribou that were in proximity to the road (<2 km) ranged from one caribou to 18 caribou each year with overall sample sizes varying from 11 to 66 each year (Table 8). Sample sizes of collars on females was at least double that of males in all years.

Table 8. Sample sizes of collared caribou as a function of closest distance from the road (prior to 2016) and built road (after 2016). Sample sizes used in the base model were based on caribou within the zone where habitat data was available (Figure 11).

Year	Closest location of collared caribou to road each year					Collars in analysis
	<2 km	2-20 km	>20-50km	>50-70 km	Total	
2005	3	6	1	1	11	11
2006	10	2	4	3	19	19
2007	9	4	11	7	31	31
2008	12	11	17	4	44	44
2009	18	16	16	12	62	62
2010	4	12	17	6	39	39
2011	5	3	11	5	24	24
2012	6	13	18	7	44	44
2013	4	5	9	2	20	18
2014	1	7	7	2	17	17
2015	2	7	2	1	12	12
2016	3	13	21	10	47	43
2017	7	17	8	6	38	35
2018	2	17	32	23	74	66
2019	1	11	14	12	38	34
2020	1	2	17	7	27	24

Caribou Movement Rate

Movement rate was summarized for male and female caribou (herds pooled) for each year to define available habitat for the RSF analysis. In general, females moved more per day than males, as indicated by the 95th percentile of distances moved per day (Figure 15). In the more recent data set, fix interval varied from four to 24 hours (intervals >24 hours were not used). To accommodate the various data sets, availability was also based on fix interval (with 95th percentile listed in red above each box plot). These distances were used to define available habitat for the RSF analysis.

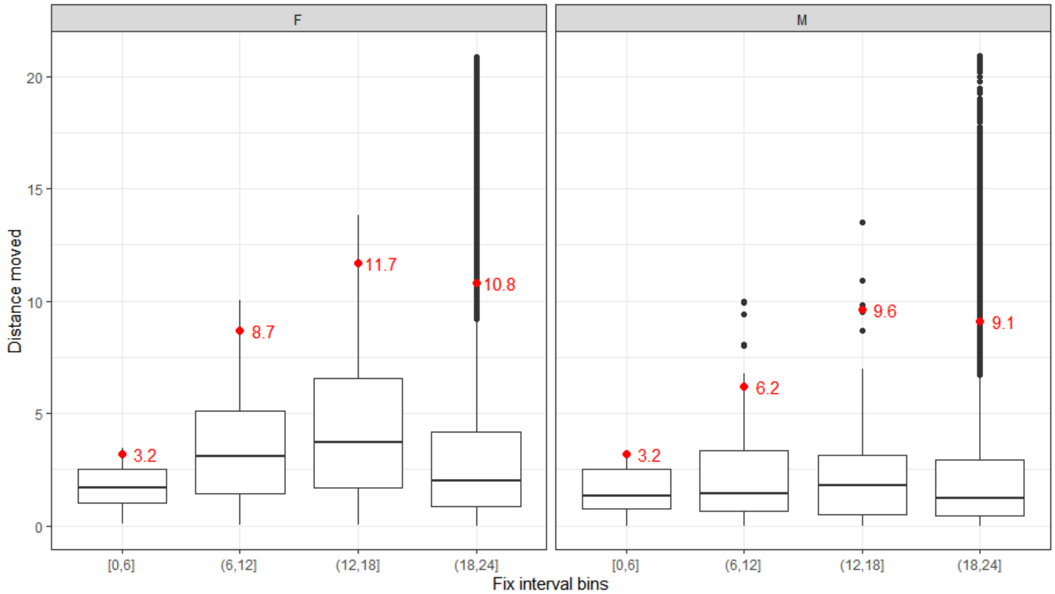

Figure 15. Boxplots of distances moved by caribou as a function of fix interval and sex of caribou. Data from herds were combined for this summary. The red points and numbers indicate the 95th percentile of points used to delineate available habitat in the RSF analysis.

Appendix 3. Resource Selection Function Habitat Model Details

Development of Baseline Model using Pre-road Data

An RSF analysis was used to formulate the baseline model for the analysis. In its simplest form, a RSF analysis estimates how a given habitat type would be selected if offered in equal proportion to other habitat types (Manly et al. 1993).

The relative proportion of habitat types in a 500 m buffer radius (the maximum error of the GPS collars) around collar locations was estimated for each caribou location. Each buffered point was compared with the buffered area around five random points that were within a specified distance from the previous location of the collared caribou. The circle was the "availability radius", defined by the 95th percentile of the distance moved (Figure 15) for caribou between successive point (Arthur et al. 1996). The actual size of the buffer depended on the interval between fixes and sex of caribou as shown in Figure 15.

Habitat covariates were standardized by their mean and standard deviation ($x' = [x - std(x)]/\bar{x}$), which expressed each covariate in units of standard deviation for all data used in the analysis. This approach helped accommodate different scales of covariates (e.g. elevation and proportion habitat) and made it possible to compare the coefficients of each covariate in the model (since they were all in units of standard deviation). Tests for significance of the main RSF model covariates were conducted with and without standardized variables to assess if standardization affected overall model results.

Caribou location points (used) and random points were modeled using conditional logistic regression (Hosmer and Lemeshow 2000). The analysis defined each used and five accompanying random points as a cluster. This cluster centered each comparison on the habitat available to the caribou at the time at which the location was recorded. Potential underestimation of parameter variances due to autocorrelation between repeated yearly points of individual caribou was modeled using a GEE variance estimator (Pendergast et al. 1996, Koper and Manseau 2009).

Because the model is based on used versus random locations, it is not possible to estimate probability of use given that some of the random locations may have been utilized by caribou. For this reason, all estimates were interpreted as odds ratios which is the exponent of each of the slope terms (Manly et al. 1993, Johnson et al. 2006). An odds ratio of 1 would imply that the given habitat is not selected. If the odds ratio was <1, then the habitat was avoided, whereas an odds ratio of >1 would imply that the habitat is selected.

Development of the Base Habitat Model using Pre-road Data

The building of a baseline RSF model was conducted in a sequential process using caribou collar location data from prior to development of the road. First, univariate tests were conducted to test the general relationship between predictors and selection as well as whether there was sex or herd-specific selection for a given habitat covariate (x). Herd-specific selection could occur if the two herds utilized different areas during the winter, which might affect their selection of certain habitat types. Sex-specific selection could occur if there was sex-specific segregation that might also affect habitat selection. Month-specific selection could be caused by changes in habitat types in late winter. The basic univariate RSF model tested was of the form:

$$Response\ (used/random) = x + x^2 + sex*x + herd*x + month*x + year*x$$

The x term was used to test a linear response while the x^2 terms tested a quadratic response, indicating that an intermediate value of the covariate was selected (or not selected). The sex- and herd-interaction terms determined whether habitat selection differed by caribou herd or sex. Month and year terms tested for differential selection by month. Month terms were considered as categorical and linear terms. If the categorical term was not significant, then a linear term was tested to determine if there were directional trends. In all cases, results were evaluated graphically as well as with significance tests.

The terms that were significant from the univariate tests were then combined into a larger RSF model. Aspect was also introduced into the model as a categorical term (Flat, SE, SW, NE, and NW). Type 3 tests, which are not affected by the order of parameters in the model, were then used to determine the overall significance of the habitat terms (SAS Institute 2000).

Habitat coverage was summarized by used and random locations for male and female caribou (Figure 16). The study area was dominated by dwarf shrub, water, wet graminoid, and woodland needle leaf habitat types. In many habitat types, the proportion of used habitat types versus random availability of habitat types was different suggesting habitat selection (as tested in the RSF model exercise). Seasonal selection was considered using an interaction of habitat type and month.

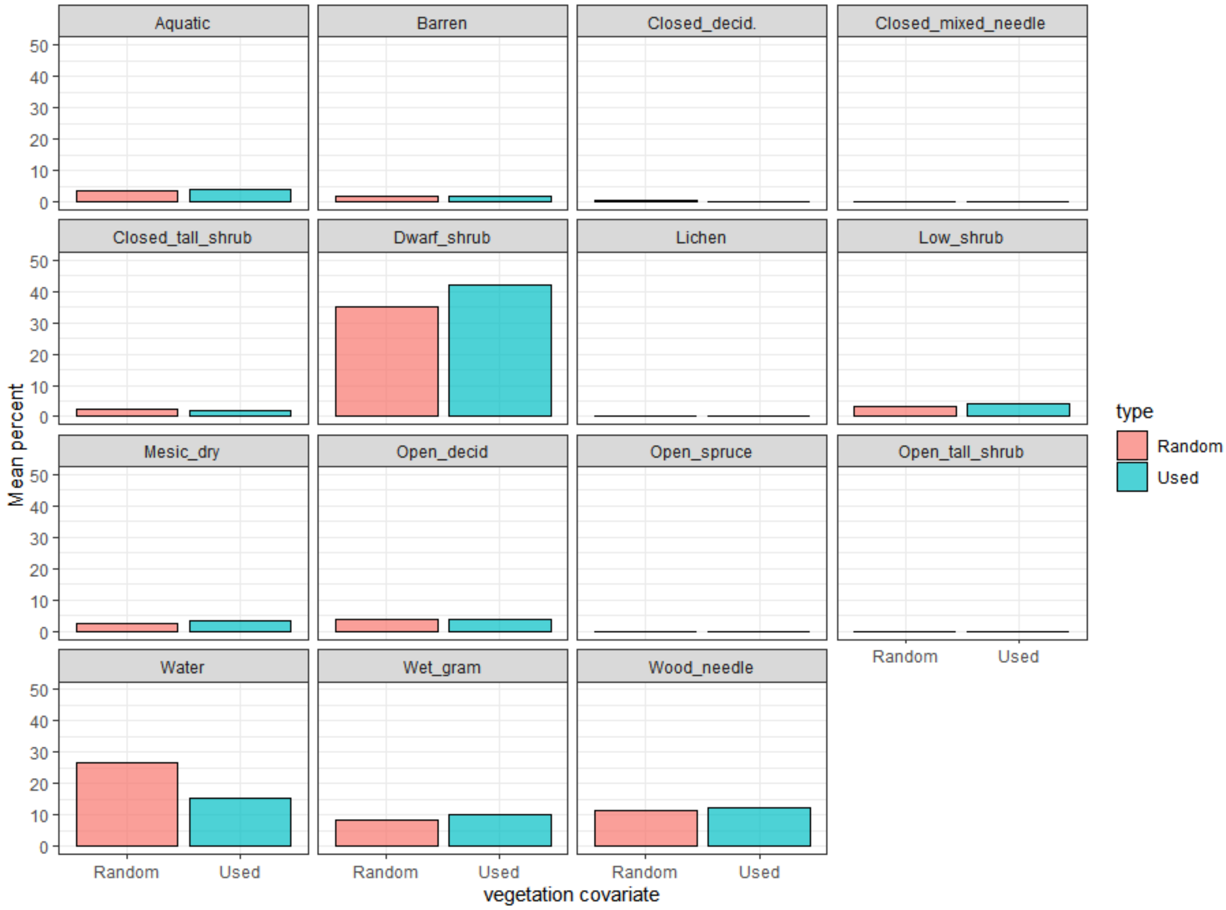

Figure 16. Summary of used versus random locations for caribou locations and habitat types.

The base model was developed using data up to 2013 which involved univariate testing of each covariate followed by the building of a multivariate base model. The base model was then applied to the more recent data set that included 2014-2020 location data (when the road was being built or operating). Model parameters from the original base model were significant when the newer data set was applied (Table 3).

Univariate Tests

Univariate tests revealed that there was minimal sex-specific, year-specific, or month-specific selection for habitat covariates, as indicated by lack of parameter significance in univariate tests (at α =0.05) (Table 9). Many of the covariates displayed both linear and quadratic significance, suggesting that selection occurred at intermediate values of each covariate. There was also herd-specific selection for some of the terms.

Table 9. Summary of univariate tests of the association between caribou habitat selection and habitat covariates. Odds ratios for each term (exponent of slope terms) are given. Only significant terms are shown.

Covariates (X)	Significant model terms		
	Linear *(X)*	Quadratic *(X^2)*	*X*herd*
Aquatic	1.69	0.85	.
Barren	1.82	0.86	0.76
Closed deciduous	.	1.01	.
Closed tall shrub	1.26	0.94	.
Elevation	2.35	.	.
Dwarf shrub	2.57	0.65	0.71
Lichen	1.48	0.97	.
Low shrub	2.00	0.82	.
Mesic dry	2.12	0.89	.
Open deciduous	1.62	0.93	.
Open spruce	.	0.97	.
Open tall shrub	1.38	.	0.75
Slope	1.75	0.87	0.85
Water	0.39	0.54	1.57
Wet graminoid	2.07	0.88	.
Woodland	1.70	.	.

The univariate tests were simplistic in that they assumed that a given habitat covariate was the main factor affecting selection and for this reason these tests should be interpreted cautiously. The candidate terms were then tested in a full RSF model which made the more realistic assumption that habitat selection is related to more than one habitat covariate.

Full Habitat Model

Initial analyses considered the full extent of the habitat classification coverage (Figure 11). However, after preliminary analyses, the area considered was reduced to used (and accompanying random) locations that occurred within 50 kilometers of the proposed road. This approach minimized edge effects on random point locations located near the border of the habitat coverage as well as the influence of wooded habitat classes to the east. The initial analysis using the full extent of coverage is summarized later in this document.

The full RSF habitat model (Table 10) suggested selection for habitat variables including aspect and nine of the 16 covariates considered from the univariate analysis (Table 9). Some covariates significant in univariate analyses were not significant in full model analyses due to the influence of other covariates. Northeast and northwest aspects were more likely to be selected than southeast and flat aspects. In many cases, linear and quadratic terms were supported, suggesting non-linear habitat selection. Herd-specific selection was suggested for some covariates, which was presumably due to different areas utilized by the two herds during the winter season. The SE ratio for all coefficients, which is the amount the variance was inflated due to correlated locations, was >1, demonstrating the effect of correlation of repeated fixes on naïve estimates of SE. Terms were significant when the model was run with standardized and non-standardized covariate values.

Table 10. RSF habitat model for caribou habitat selection within 50 kilometers of the ITH. Standardized logit-scale parameters are given along with SE, the inflation factor of SE due to autocorrelation of estimates (χ^2), and p-value of chi square test (p(χ^2)).

Parameter	Category	DF	Estimate	SE	χ^2	P(χ^2)
Aspect	SW	1	0.30	0.03	10.29	<0.0001
	NE	1	0.34	0.03	12.86	<0.0001
	NW	1	0.30	0.02	12.03	<0.0001
	SE	1	0.30	0.03	10.91	<0.0001
Barren^2		1	-0.01	0.00	-3.08	0.0021
Barren*herd	CB	1	0.07	0.03	2.59	0.0097
Closed tall shrub^2		1	-0.05	0.01	-7.12	<0.0001
Elevation^2		1	-0.05	0.01	-4.01	0.0001
Dwarf shrub		1	0.06	0.03	1.83	0.0671
Dwarf shrub*herd	CB	1	0.21	0.04	5.37	<0.0001
Low shrub		1	0.06	0.02	2.46	0.0139
Low shrub^2		1	-0.03	0.01	-4.14	<0.0001
Open deciduous		1	-0.13	0.02	-7.51	<0.0001
Open spruce^2		1	-0.01	0.00	-2.37	0.0176
Slope^2		1	-0.01	0.00	-4.60	<0.0001
Water		1	-0.69	0.06	-10.72	<0.0001
Water^2		1	-0.36	0.02	-19.14	<0.0001
Water*month		1	0.08	0.01	7.52	<0.0001

The best way to evaluate selection for the non-linear terms is to plot the standardized coefficients across the range where most of the covariate values occurred, as defined by the minimum and 95th percentile of individual covariate values (Figures 17, 18). For this comparison, aspect was set at flat, which has a baseline odds ratio of 0.7. Therefore, any odds ratio above 0.7 would indicate positive selection whereas values below would indicate negative selection. Odds ratio was fixed at 0 when the standardized value for the covariate was 0. In terms of aspect, open northeast and northwest aspects were selected more than southern or flat aspects (Figure 17). Selection was positive for low shrub and lichen and negative for higher values of closed tall shrub, open spruce, and open deciduous. In terms of geography, there was weak selection for moderate elevations and slopes.

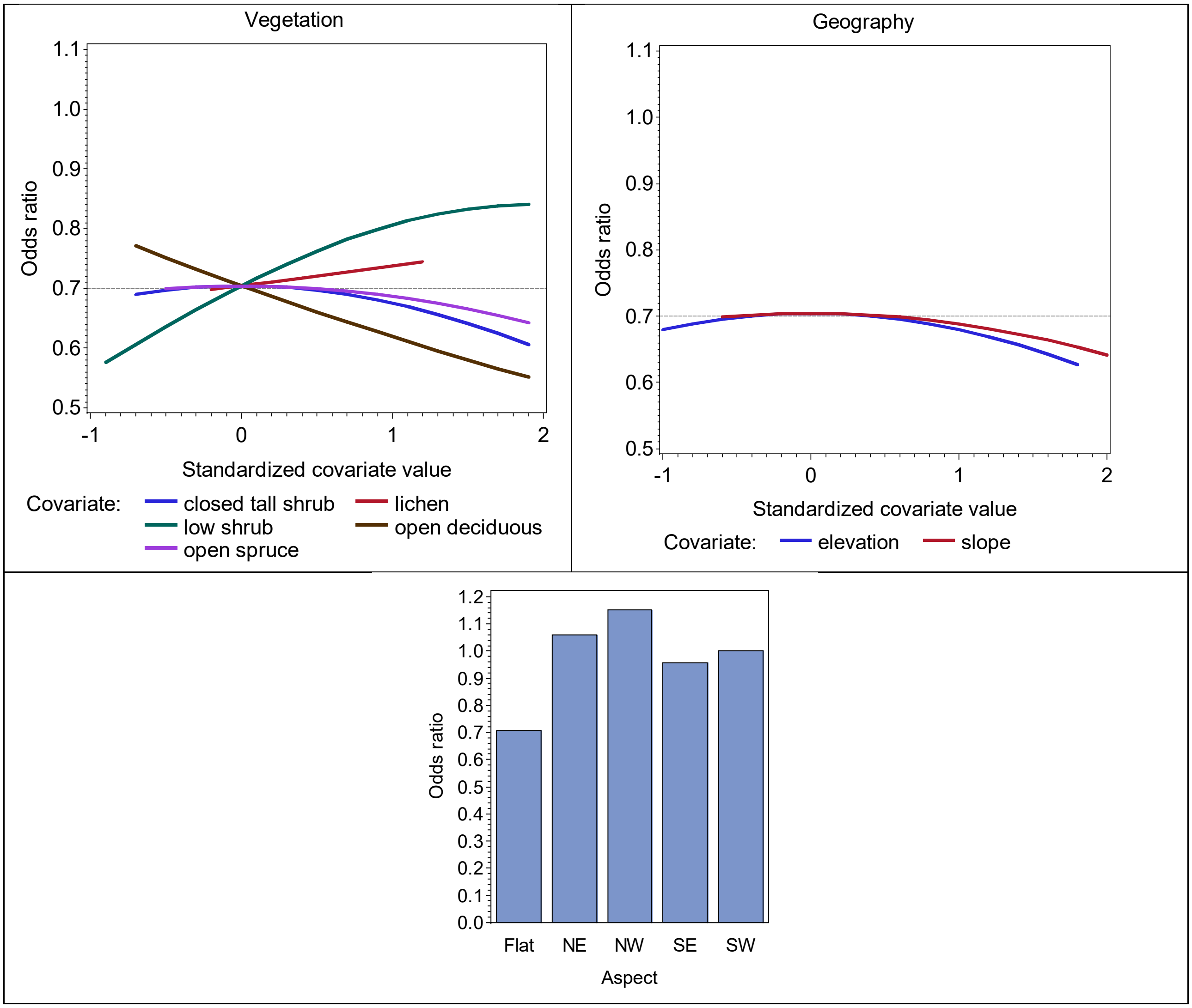

Figure 17. Relationships between covariates and habitat selection for additive terms based on standardized values of covariates with other covariates set at mean levels for the model listed in Table 10. Each standardized unit represents one unit from the standardized mean that is set at 0.

Some terms were most significant as interactions (Figure 18). Dwarf shrub was positively selected by the Tuktoyaktuk Peninsula herd with less notable selection by the Cape Bathurst herd. Barren ground was negatively selected by the Cape Bathurst herd compared to the Tuktoyaktuk Peninsula herd. In general, there was negative selection for water except for slight positive selection in December for lower than mean levels. Negative selection was most pronounced at low and high levels. The negative selection shifted to higher values increasingly as the study progressed from December to April potentially due to seasonal changes.

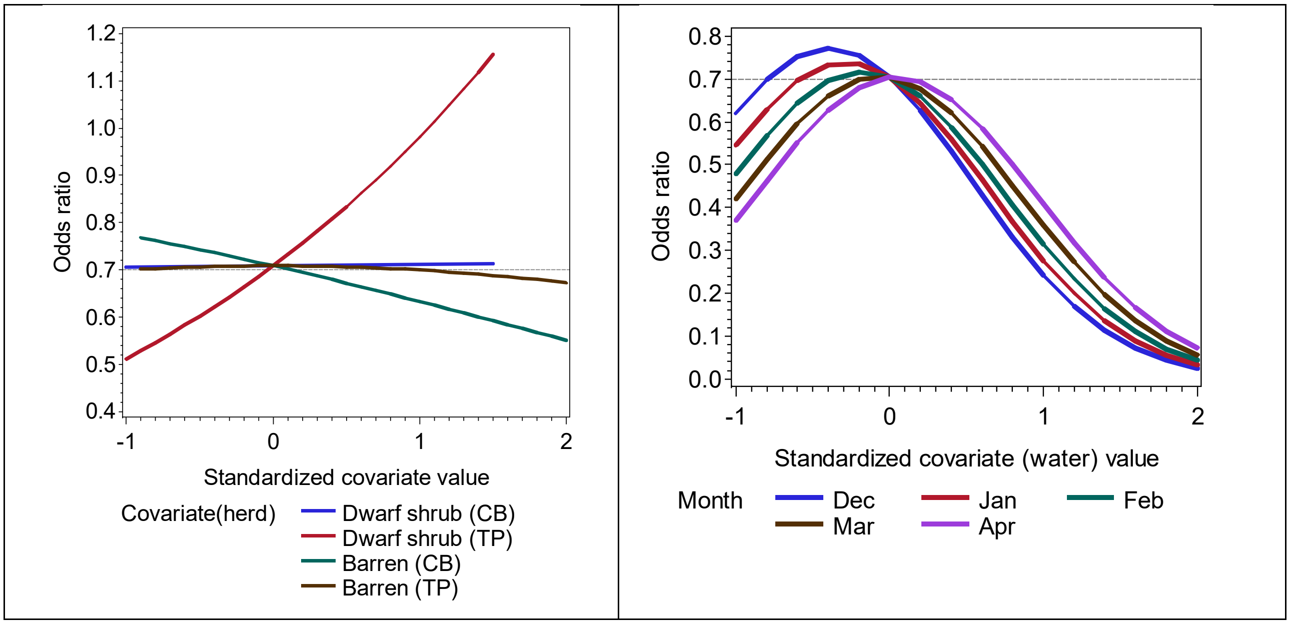

Figure 18. Relationships between covariates and habitat selection for interaction terms based on standardized values of covariates with other covariates set at mean levels and a flat aspect for the model listed in Table 10. Each standardized unit represents one unit from the standardized mean that is set at 0. The vertical line at 0.7 represent no selection with values above indicating positive selection and values below indicating negative selection.

Goodness of Fit of the RSF Model

Test and training data sets were used to assess the goodness of fit of the RSF model. For this approach, 18% of the used (and paired random) locations were withheld as a "training" data set with the remaining 82% used to estimate model parameters. Predictions were then generated using the test data set to determine how well the model performed with the test data. Predicted odds ratios of used and random locations were binned by successive RSF category as exemplified in Figure 19. The proportion of used locations increased with each category.

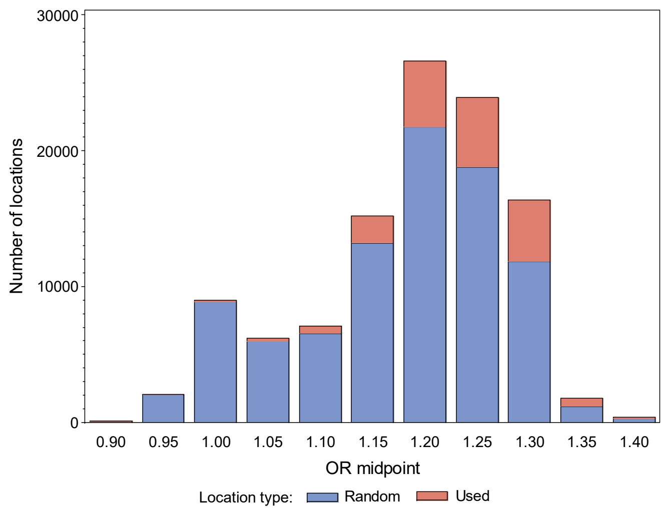

Figure 19. Example of goodness of fit test with higher frequencies of used points for higher odds ratio bins for a test data set.

Predicted Habitat Selection

The RSF model was projected to the study area map using just the used locations (Figure 20) and the used and random locations (Figure 21) to demonstrate delineation of water/frozen lake areas as areas that were not selected. Grey areas on these maps indicated areas less likely to be selected (OR<1) with colored areas suggesting areas of positive selection.

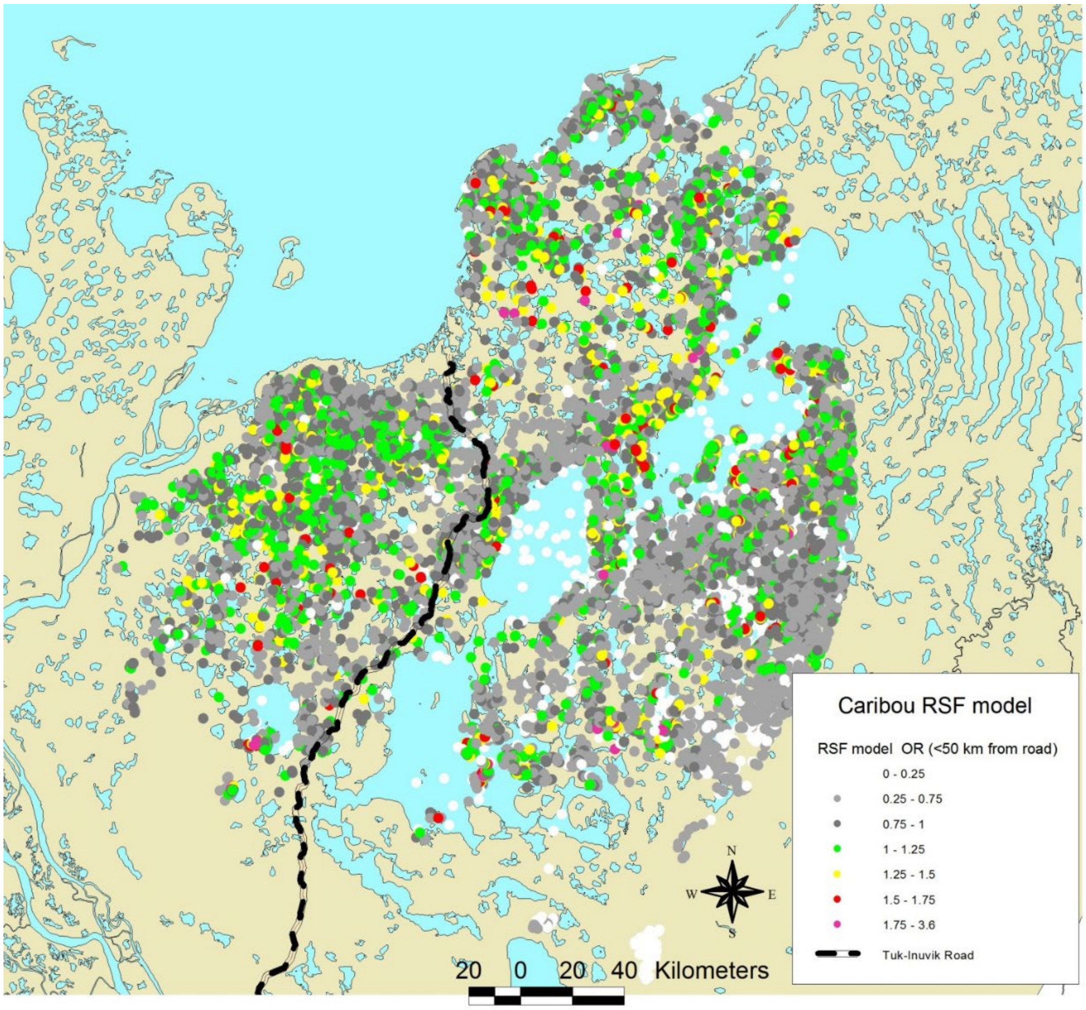

Figure 20. Map of RSF model predictions as predicted from used locations of collared caribou (sexes and herds pooled). Predictions are given as odds ratios. If the odds ratio is <1 then habitat is less likely to be selected. If odds ratio is >1 then habitat is more likely to be selected.

A band of habitat that runs parallel to the western side of the road as well as the presence of frozen lakes on the eastern side displayed reduced habitat selection. This finding illustrates the need for a baseline habitat model to account for these differences in habitat selection therefore avoiding potential confounding of effects of the road.

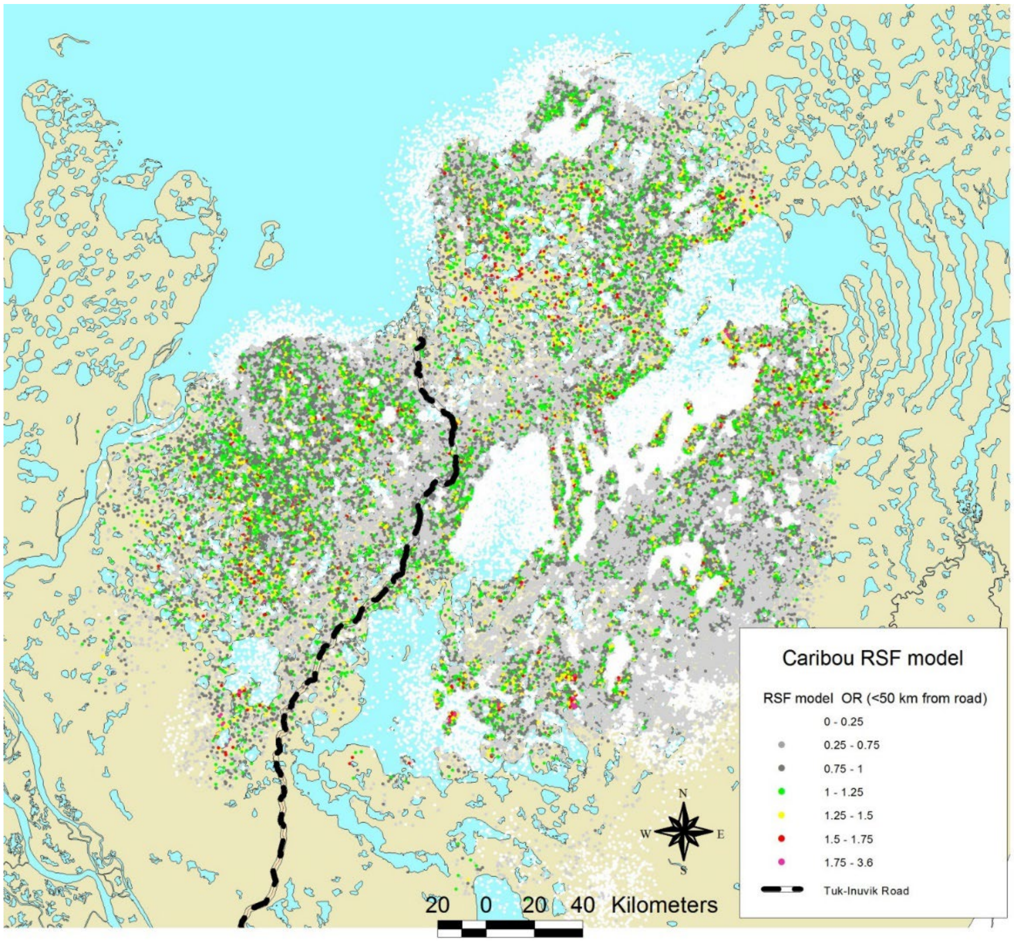

Figure 21. Map of RSF model predictions as predicted from used and random locations of collared caribou (sexes and herds pooled). Predictions are given as odds ratios. If the odds ratio is <1 then habitat is less likely to be selected. If odds ratio is >1 then habitat is more likely to be selected.

Goodness of Fit of RSF Model Fit to Pre- and Post-road Data

The initial baseline habitat model was then applied to location collected during the building of the road and after the road was built as detailed in the main report. An additional goodness of fit test was conducted to verify that the baseline model fit the newer data sets. As with the previous analysis, goodness of fit of the baseline RSF model to the full data set was tested using k-fold cross validation (Boyce et al. 2002). For this analysis, the data was subdivided into training and testing data sets based on Huberty's rule of thumb (Huberty 1994). The goodness of fit of a model developed with the training data set was then tested with the testing data set. The Pearson correlation (Zar 1996) of successive RSF score bins with the frequency of used locations in each bin (adjusted for availability area of each bin). If the model fit the data then the RSF bin score and area-adjusted frequencies should be positively correlated (Boyce et al. 2002). This process was repeated 100 times using bootstrap resampling (Manly 1997) to ensure that the cross validation was minimally affected by the division of testing and training data sets.

The model was cross validated with observed (using model testing data) and expected frequencies (using training data) of locations being compared for each year (Figure 22, Tables 11-12) and month (Figure 23, Tables 13-14) of the analysis. Correlation between observed and expected in binned interval was significant in all years, with median correlations above 0.9 for all years. There was more variation in 2015 than other years suggesting lower fit for this year.

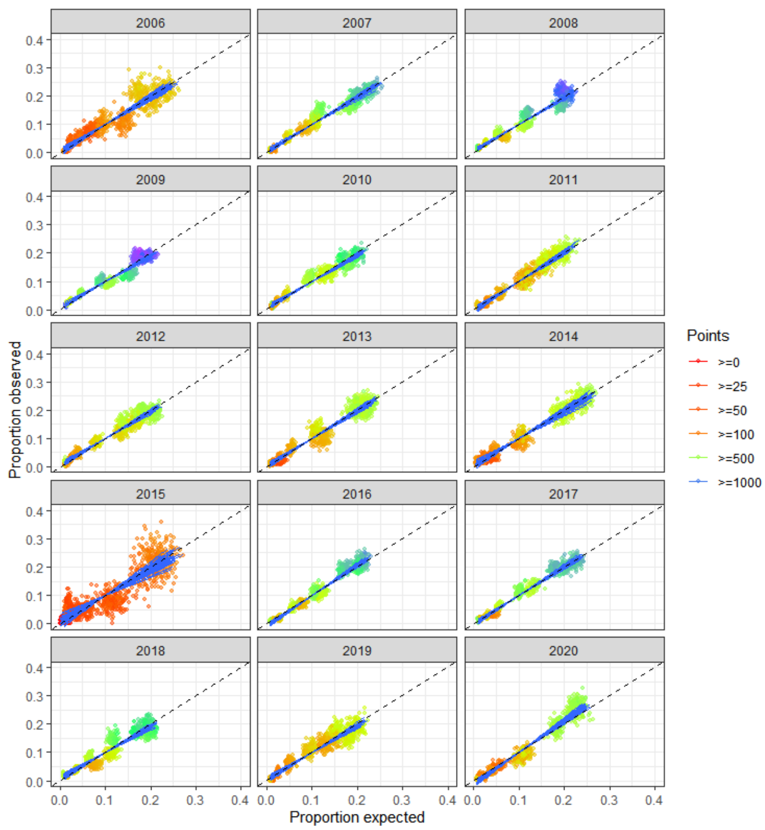

Figure 22. Observed (using testing data) and expected (using model predictions from training data) from 100 cross-validation trials by year of collar data. If model fits the data adequately most observations (points) and the slope of the observed-expected relationship (blue line) should lie on the 1:1 agreement line (dashed diagonal line).

Table 11. Summary of correlation test of observed and expected frequencies for 100 cross-validation iterations.

Year	Mean	Median	Min	Max	lcl	ucl	Proportion significant
2006	0.89	0.90	0.63	0.97	0.78	0.96	1.00
2007	0.96	0.96	0.92	0.99	0.92	0.99	1.00
2008	0.94	0.94	0.84	0.98	0.87	0.97	1.00
2009	0.96	0.96	0.91	0.99	0.92	0.98	1.00
2010	0.97	0.97	0.86	1.00	0.91	0.99	1.00
2011	0.97	0.97	0.91	0.99	0.92	0.99	1.00
2012	0.96	0.96	0.90	0.99	0.91	0.99	1.00
2013	0.86	0.89	0.58	0.99	0.62	0.98	1.00
2014	0.90	0.92	0.61	0.99	0.71	0.99	1.00
2015	0.51	0.66	-0.19	0.90	-0.04	0.89	0.63
2016	0.97	0.97	0.92	0.99	0.94	0.99	1.00
2017	0.93	0.94	0.80	0.99	0.83	0.99	1.00
2018	0.91	0.92	0.76	0.98	0.80	0.97	1.00
2019	0.95	0.95	0.88	0.99	0.90	0.98	1.00
2020	0.94	0.94	0.84	0.99	0.85	0.98	1.00

Table 12. Summary of regression of observed and expected frequencies. If fit is perfect, then the slope should = 1 and confidence limits should overlap 1

Year	Mean	Median	Min	Max	lcl	ucl
2006	0.93	0.93	0.71	1.08	0.79	1.05
2007	0.99	0.98	0.92	1.08	0.94	1.05
2008	0.99	0.99	0.91	1.09	0.92	1.07
2009	1.02	1.03	0.93	1.10	0.95	1.09
2010	1.03	1.03	0.95	1.14	0.96	1.10
2011	0.93	0.93	0.82	1.04	0.83	1.01
2012	0.99	0.99	0.89	1.09	0.90	1.06
2013	0.97	0.96	0.85	1.08	0.88	1.06
2014	1.02	1.02	0.84	1.21	0.92	1.13
2015	0.89	0.88	0.62	1.29	0.65	1.15
2016	0.91	0.90	0.81	0.99	0.85	0.97
2017	0.97	0.97	0.88	1.06	0.90	1.03
2018	0.98	0.98	0.83	1.11	0.87	1.07
2019	0.97	0.97	0.85	1.08	0.87	1.05
2020	0.85	0.86	0.77	0.94	0.78	0.93

Cross validation by month allowed a test of whether the model adequately described seasonal variation in habitat selection (Figure 23). Slopes were significant for all months with slightly lower fit in October and May. However, the median correlation coefficient for all years was greater than 0.9 suggesting overall adequate fit.

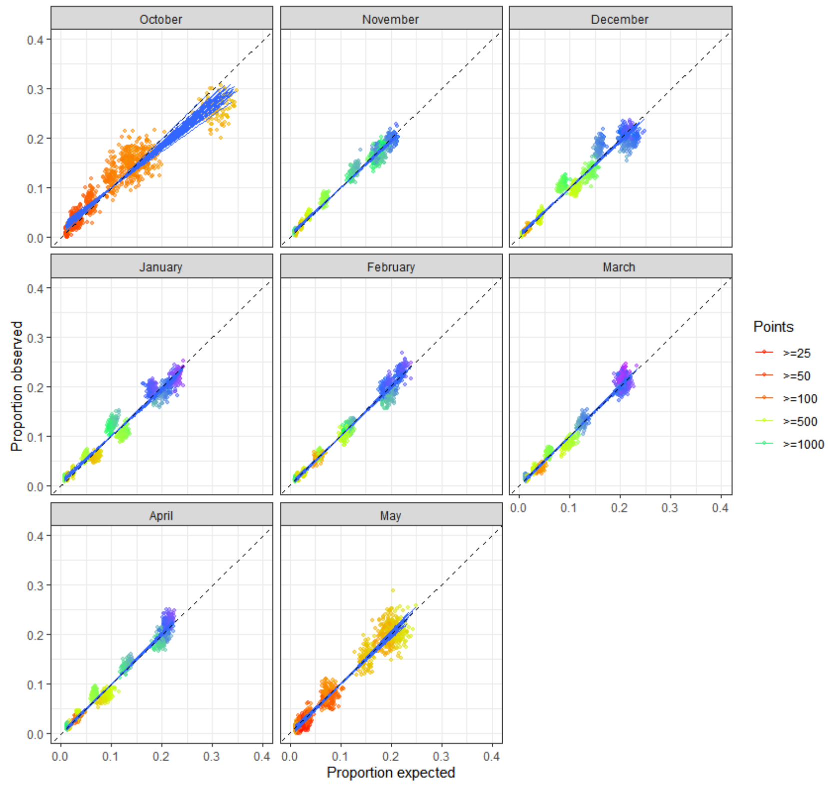

Figure 23. Observed (using testing data) and expected (using model predictions from training data) from 100 cross-validation trials by month of collar data (years pooled). If model fits the data adequately most observations (points) and the slope of the observed-expected relationship (blue line) should lie on the 1:1 agreement line (dashed diagonal line).

Table 13. Summary of correlation test of observed and expected frequencies for 100 cross-validation iterations.

Month	Mean	Median	Min	Max	lcl	ucl	Proportion significant
10	0.90	0.91	0.72	0.98	0.78	0.97	1.00
11	0.98	0.98	0.95	1.00	0.96	0.99	1.00
12	0.96	0.97	0.92	0.99	0.93	0.98	1.00
1	0.96	0.96	0.92	1.00	0.93	0.99	1.00
2	0.98	0.99	0.94	1.00	0.96	1.00	1.00
3	0.97	0.97	0.87	0.99	0.92	0.99	1.00
4	0.97	0.97	0.92	1.00	0.93	0.99	1.00
5	0.84	0.89	0.47	0.99	0.56	0.98	0.98

Table 14. Summary of regression of observed and expected frequencies. If fit is perfect, then the slope should = 1 and confidence limits should overlap 1

Month	Mean	Median	Min	Max	lcl	ucl	Proportion significant
10	0.90	0.91	0.72	0.98	0.78	0.97	1.00
11	0.98	0.98	0.95	1.00	0.96	0.99	1.00
12	0.96	0.97	0.92	0.99	0.93	0.98	1.00
1	0.96	0.96	0.92	1.00	0.93	0.99	1.00
2	0.98	0.99	0.94	1.00	0.96	1.00	1.00
3	0.97	0.97	0.87	0.99	0.92	0.99	1.00
4	0.97	0.97	0.92	1.00	0.93	0.99	1.00
5	0.84	0.89	0.47	0.99	0.56	0.98	0.98

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