Kivalliq Caribou Monitoring Program - Analysis of Caribou Movements Relative to Meadowbank Mine and Roads During Spring Migration

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1.0 ABSTRACT

Arctic caribou play an important role in the ecosystem dynamics of the north and are of key cultural significance to Inuit. Caribou in Canada's arctic are exposed to several external pressures including, but not limited to, industrial development. This report provides an update to previous analyses of the spring movements and distribution of collared caribou in relation to the Meadowbank mine's 100 km all-weather access road and the 55 km Whale Tail expansion road (Kite et al. 2017). The analysis focuses on recent collar data (2011-2019) from the Lorrilard, Wager Bay, and Ahiak herds which provided 6 daily locations (for2015-9). Spring collar data available prior to 2011 was limited thus creating challenges in analytical development. In this analysis, we further developed the segmented regression approach used in Kite et al (2017) to estimate the zone of influence (ZOI) of the two mining roads using data from all the herds that encountered the roads during spring migration. Zone of influence is a statistical measure of spatial extent and magnitude of the influence of roads or mine footprints on caribou movements. We also re-applied biased correlated walk methods to further explore the response of caribou to the roads. We developed a new metric $\Delta D_{mine,}$ which measures the daily change in distance from mine roads for each collared caribou as they approach and cross the roads during migration. We tested for and estimated potential delays in migration due to road crossing using a regression-based and a bias correlated random walk approach. For the zone of influence analysis, we first developed a model to describe natural variation in movements. We found yearly differences in migration movement rates related specifically to the roads, but also to weather (daily temperature), and habitat (frozen areas predominantly small water bodies). From this we estimated zones of influence of 16-17 km prior to crossing for the spring of 2018 and 2019. We also found that caribou increased movement rates after crossing the road up to 2.6 km east of the road. Zones of influence were not detected from 2011-6, however, data from these years was limited in terms of sample size (less than 10 caribou collared per year) which likely reduced power to detect and estimate ZOI. In addition, in 2011-6, prior to building of the Whale Tail road (primarily in 2017-8), 55% (12 of 22) of collared caribou deflected north around the AWAR/Meadowbank mine rather than crossing either road. Upon building the Whale Tail road this path around the AWAR road was cut off leading to significantly lower (14%) deflections (3 of 23 caribou) which made caribou 8.3 times more likely to cross rather than deflect around the road therefore increasing ZOI's. Using the zone of influence estimates, we used a regression approach to estimate delays in crossing when a zone of influence was detected. Estimates of delay were 4.3 and 2.5 days for 2018 and 2019 respectively. We note that the estimates of delay were based upon periods where roads were open and closed. We further tested if road closure during 2018 and 2019 influenced delays and found that closing roads increased the probability of caribou crossing the road, with probabilities of movement across the road being most increased within 10-12 km from the road, and prior to crossing the road. It is therefore predicted that delays in crossing open roads will be greater than the overall means presented in this analysis which were not specific to road status. Estimates of delay from the bias correlated random walk were significantly correlated with those from regression approaches therefore providing a cross-validation of the general approach developed in this analysis. The results of this analysis suggest that the road delayed migration in 2018 and 2019 which may have been partially due to the presence of both the AWAR and more

recent presence of Whale Tail roads. We suggest that the analysis tools developed in this paper can be used to estimate the spatial and temporal effects of the road on caribou migration given large enough sample sizes. In addition, these methods can be used to assess mitigation strategies such as road closure as to their effectiveness in reducing delays. Deficiencies in this study were lack of traffic volume data as well as a limited number of years (2) where the Whale Tail road was present. We suggest that further study with actual traffic volume data when the Whale Tail road is in full operation is needed to understand the impact of the Whale Tail road expansion.

2.0 INTRODUCTION

Arctic caribou play an important role in the ecosystem dynamics of the north and are of key cultural significance to Inuit while playing an important role in food security for northern people. Caribou in Canada's arctic are exposed to a number of external pressures including, but not limited to, industrial development (Fiesta-Bianchet et al. 2011). Because of these inevitable interactions between caribou and industry, it is important to improve our understanding of how, and to what extent, these interactions can impact this species behaviour, and ultimately, its persistence on the northern landscape. In particular, infrastructures with variable permeability such as roads, have been proven to influence caribou movement patterns (Wilson et al. 2016). Potential caribou responses may include reducing speed during migrations, disrupting selection and use of migration corridors, distributional shifts away from optimal seasonal habitat (including wintering and/or calving grounds), distributional shifts away from available habitat, and as a result, loss of harvesting opportunities within traditional hunting areas (Starikowich 2008, Panzacchi et al. 2011, Boulanger et al. 2012, Panzacchi et al. 2012, Plante et al. 2018, Johnson et al. 2019). However, without detailed spatial and temporal analysis, it is unclear where, when, and to what magnitude caribou and the people that rely on them, may be impacted by industrial features and activities. Spatial and temporal data offer information valuable to making informed and efficient management decisions to balance sustainable, healthy caribou populations with economic development in Nunavut. This is a requirement under the Nunavut Agreement and an expectation of Inuit and Canadians. Therefore, monitoring the dynamics between caribou populations and human development are a prerequisite to effective management and mitigation efforts.

This report provides an update to previous analyses on the Meadowbank road (Kite et al. 2017) utilizing recent collar data from the Lorillard, Wager Bay and Ahiak herds which have higher fix rates than earlier data sets. In this analysis we further develop the segmented regression approach used in Kite et al (2017) to estimate the zone of influence (ZOI) of the road, estimate potential delays due to the road, and the effect of road closure on crossing behaviour. We also re-apply biased correlated walk methods to further explore response of the caribou to the road. The objectives of this analysis are:

1. Develop a metric to assess caribou movements relative to mine footprints and roads during periods of migration. From this, use a statistical model-based framework (segmented regression) to test statistically for zone of influence and provide estimates of uncertainty (confidence limits) for both the zone of influence and its associated magnitude/size.
2. Develop graphical methods to display the timing of migration and predicted movements, and rates of movement, relative to mine footprints and roads.
3. Use results from segmented regression analyses to estimate the amount of potential delay caused by the road and how this delay may have been influenced by environmental covariates.
4. Estimate the probability of caribou crossing the road as related to road closure for years in which road closure data was available.

5. Use established bias correlated random walk to contrast quantified predictions of caribou movement and rate of movement, from segmented regression models.
6. Provide further guidance on use of covariates to better assess mechanisms that might be influencing caribou response to the Meadowbank roads.

This report utilizes data from all 4 herds that potentially traverse the Meadowbank mine and road areas though Lorrilard herd collar data made up 64% of all collar data suggesting further telemetry studies should be considered for the Ahiak and Wager Bay caribou Herds. We therefore suggest readers consult the Kite et al (2017) report while reading this report to provide a full background on the Meadowbank mine and road analyses.

3.0 STUDY AREA

The Meadowbank Gold Mine began operating in early 2010 and is within the Northern Arctic Ecozone located in the northern Kivalliq Region of Nunavut (Figure 1). The Northern Arctic Ecozone extends over the north-eastern Kivalliq, western Baffin Island, and northern Quebec. Winters in this ecozone pass in near darkness. Snow may fall any month of the year and usually remains on the ground from September to June. The area is classified as having a low arctic ecoclimate with a mean annual temperature of approximately -11°C. Seasonal mean temperatures are 4.5°C in summer and -26.5°C in winter. The mean annual precipitation ranges between 200 and 300 mm. Much of the landscape is typified by barren plains covered in frost-patterned soils and the occasional rock outcrop (Wiken, 1986; Ecological Stratification Working Group, 1996). Typical vegetation includes a discontinuous cover of tundra plant communities dominated by dwarf birch (*Betula glandulosa*), willow (Salix spp.), northern Labrador tea (*Ledum decumbens*), Mountain Avens (*Dryas integrifolia*), and Vaccinium spp. Taller dwarf birch, willow, and alder (*Alnus spp*) occur on warm sites while wet sites are dominated by willow and sedge (*Carex spp*). Lichen-covered rock outcroppings are prominent throughout the ecoregion.

Related mine infrastructure includes: maintenance facilities, fuel storage, water and sewage treatment plants, mill, power plant, airstrip, open pits, tailings and waste rock storage facilities (Gebauer et al. 2008). An approximately 100-kilometre all-weather access road connects the hamlet of Baker Lake to the mine and supports all ground traffic to the site. Road construction between Baker Lake and the Meadowbank Mine site was completed in 2008. In 2016, construction began on the Whale Tail Expansion Project. The expansion site is located approximately 55 kilometres north of the Meadowbank mine and is connected via the Whale Tail Haul Road. Construction of the Whale Tail haul road was completed in 2018 and commercial production and hauling from this expansion pit began in 2019 (Agnico_Eagle 2019).

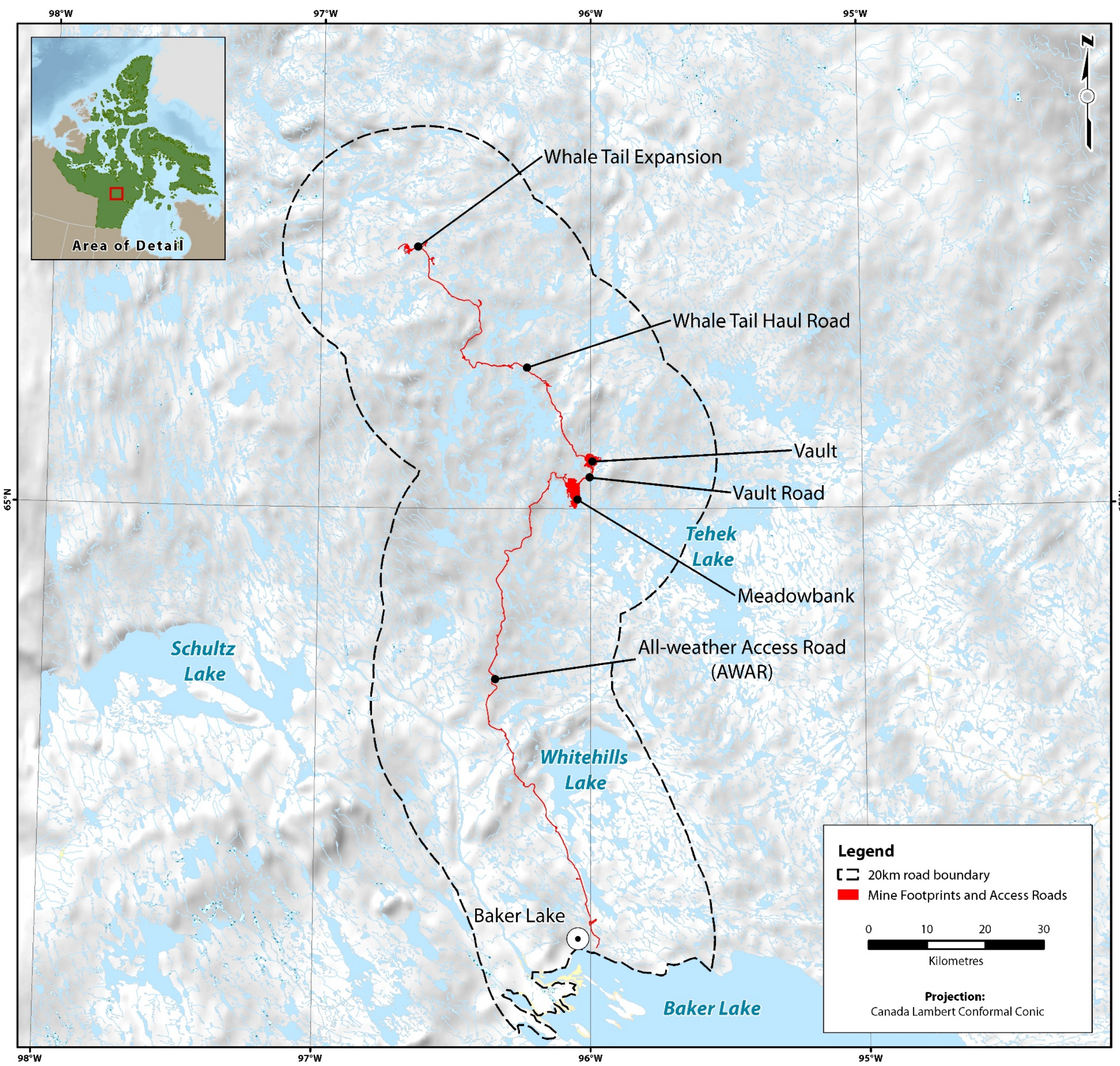

Figure 1. The Meadowbank Gold Mine is located at the north end of an all-weather access road (AWAR) that stretches from Baker Lake to the mine site. The Whale Tail haul road (brown) connects the Meadowbank site to the Whale Tail Pit expansion.

While the annual ranges of the Qamanirjuaq, Ahiak, Wager Bay, and Lorillard caribou subpopulations overlap the road, telemetry data indicates that only the Ahiak, Wager Bay, and Lorillard subpopulations specifically interact with the road and mine site (Figure 2). Seasonal distributions of these three subpopulations, show that interactions with the road are possible, primarily during the winter and high movement spring and fall migration seasons. The analyses conducted in Kite et al. 2017 were focused solely on Lorillard collared cows, as the majority of the collar data for 1998-2017 belonged to this subpopulation.

More recent collar deployments for Ahiak and Wager Bay caribou have captured a greater albeit limited number of caribou-road interactions. This collar data is analysed within this report.

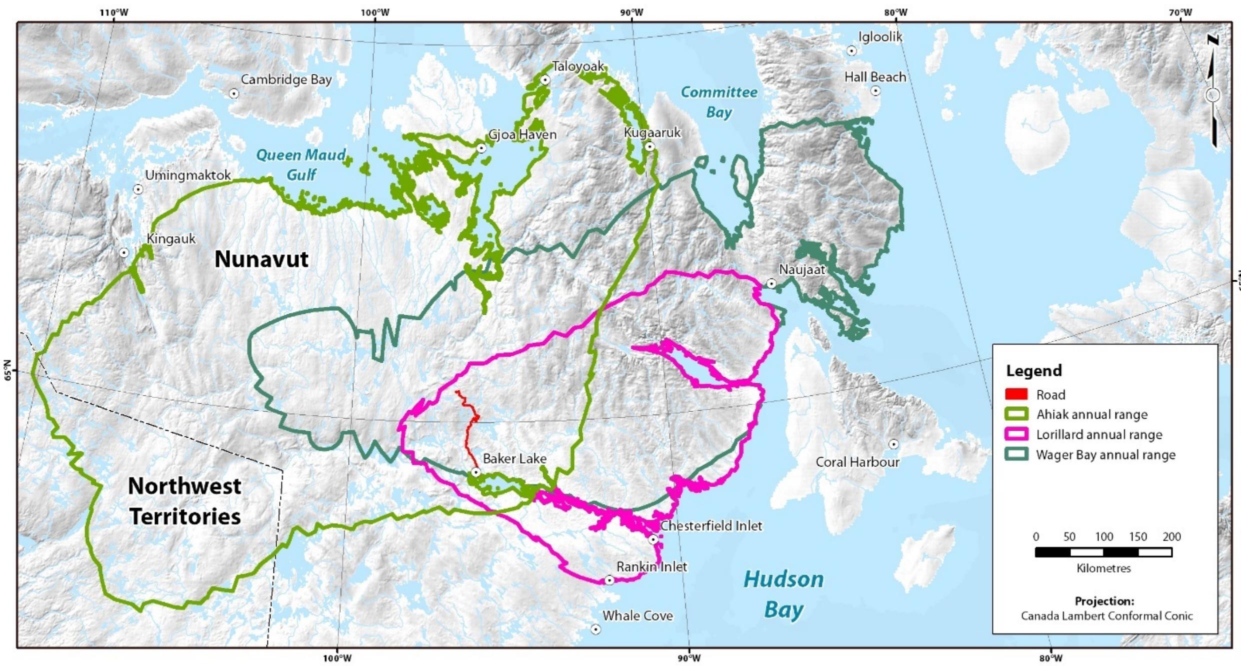

Figure 2. The annual range of three caribou subpopulations overlapping the Meadowbank road and mine site and whale tail extension (indicated hereafter as "road"). All three subpopulations are potentially affected by the road; however, of the three, the Lorillard subpopulation contains the highest sample size, and number of telemetry fixes that directly cross the road, or are within the 20km road buffer (Campbell et al. 2014).

4.0 METHODS

Various approaches were used to assess caribou movements relative to the Meadowbank road. First, regression analyses were used to assess potential changes in caribou movement characteristics in the vicinity of the road as well as to estimate a zone of influence (ZOI) of the road where movements were affected. The results of the ZOI analysis were further used to estimate potential delays in migration as well as whether reported road closures partially mitigated effects of the road. Finally, a biased correlated random walk analyses were used to estimate potential delays in crossing the road, which in turn, were used to compare with, and further validate, ZOI results.

4.1 Data screening

The primary focus of the analyses was an assessment of caribou response to Meadowbank roads, and therefore the data set was reduced to only include caribou that encountered the road. To achieve this objective, caribou that only travelled north of the road (passing > 10 km north from the road) were excluded from the analysis. Deflector caribou that came within 5 km of one of the roads but never crossed the road, instead crossing north or south of the roads, were included and considered further in the analyses. Part of the analysis involved the building of a base model to describe habitat, geographic, and weather factors that affected caribou movement. For caribou that encountered roads, we therefore included all data on their locations within 160 km from the road. This approach allowed the building of base models using data that was minimally influenced by the road. A full graphical summary of data screening procedures is given in Appendix 7.3.

The spring migration data was exclusively used for this analysis and included dates from April 1 to May 28th. In some years, live capture for collaring occurred during the spring migration. Caribou that were collared within 20 km of the road or after crossing the road, were excluded from the analysis. Caribou that were collared at > 20km from the road, were included, and potential differences in response to the road for caribou collared during the year of study was tested for as part of the analysis.

Telemetry locations from caribou in mid-June were used to assign caribou to herds based on calving ground locations (Nagy et al. 2011, Nagy and Campbell 2012). In the case of spring migration analysis, the calving ground caribou were classified based upon the calving ground they were heading to during spring migration (rather than the previous year's calving ground) given that the destination calving ground would most likely affect trajectories relative to the road.

4.2 Graphical representation of caribou paths relative to mine roads and response metrics

An essential part of the analyses in this paper is the graphical summary of how individual caribou paths relate to the different mine roads and how road closure may affect caribou crossing behaviour (Figure 3). We therefore present simplified examples of these figures to ensure that results are interpreted properly. Figure 3 first shows the path of caribou BL2018010 in 2018 and 2019. In 2018, it approached the AWAR road and then moved parallel to the road before crossing at the Meadowbank/Vault area. In 2019 it moved quickly through the area crossing on the Vault road. During 2018 and 2019 each road was intermittently closed and re-opened. The second plot, which has its date as the y-axis and distance from roads on the x-axis, demonstrates the "movement trajectory" of the caribou relative to roads, as well as the status of the roads during this time. The main difference between these two trajectories is that the change in distance relative to the road was variable in 2018, with the caribou paralleling the road and moving away from the road, whereas in 2019, the change in position was relatively constant.

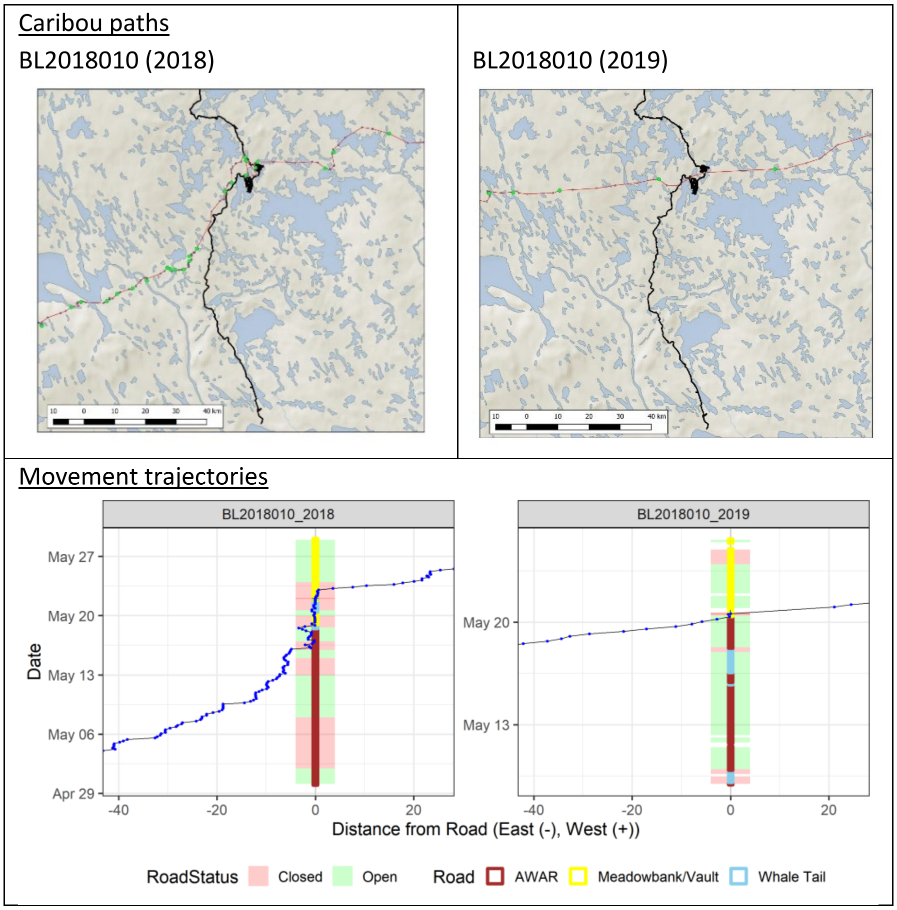

Figure 3. Path of BL2018010 in 2018 and 2019 as summarized by a movement trajectory plot.

This difference in trajectories for 2018 and 2019 can be captured by the ΔD_{mine} metric, which is the relative change in position of the caribou relative to the road at each time interval between locations (Figure 4). If the caribou moves away from the road it is negative, if it is parallel to the road it is zero, and if it moves consistently toward the road it is positive. In 2018, the distribution of ΔD_{mine} includes negative and lower values closer to the road in comparison to 2019 when most values are positive. The ΔD_{mine} metric provides a response metric to test if the road affects caribou movement. Namely, if the road does not affect caribou movements then the distribution of ΔD_{mine} should not change relative to the mine road.

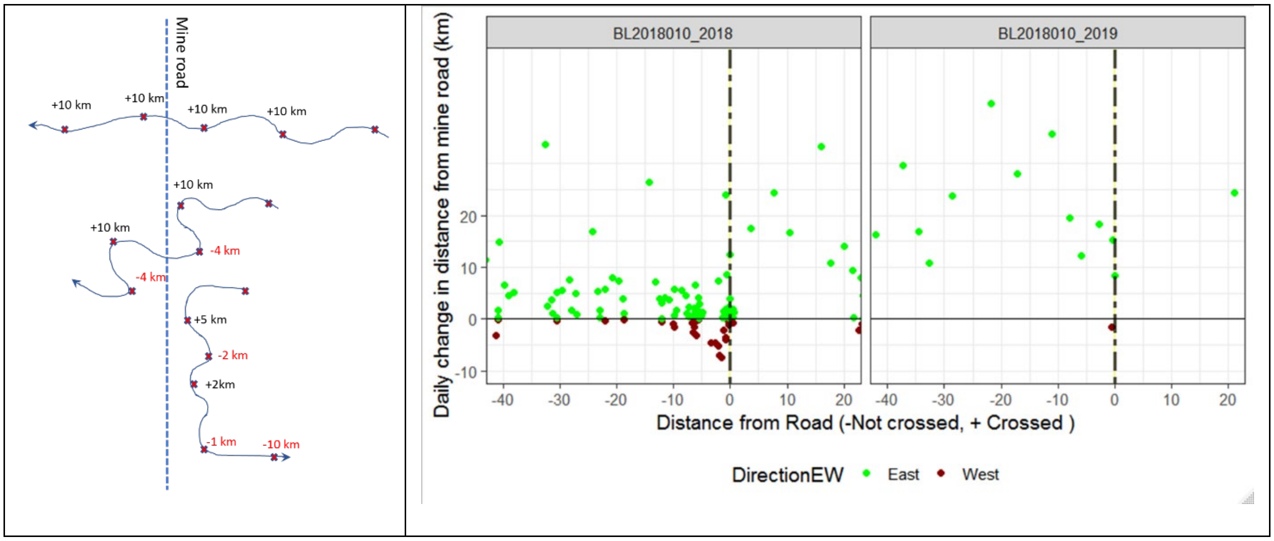

Figure 4. The distance from mine road offset metric (ΔD_{mine}). The left figure illustrates how the (ΔD_{mine}) metric values change dependent of caribou path and the right figure shows ΔD_{mine} metrics for BL201810, whose full paths are illustrated in Figure 3.

One point to note is that movement rate alone will not index delays due to roads. Figure 5 shows the same data as in Figure 4 but with movement rate rather than mine offset rate as the response y-axis variable. In this case movement rate increases in 2018 as the caribou moves parallel to the road. Therefore, movement rate is not capturing delay in migration caused by the road. Note that movement rate and mine offset are very similar for the path in 2019 when there was minimal delay caused by the road.

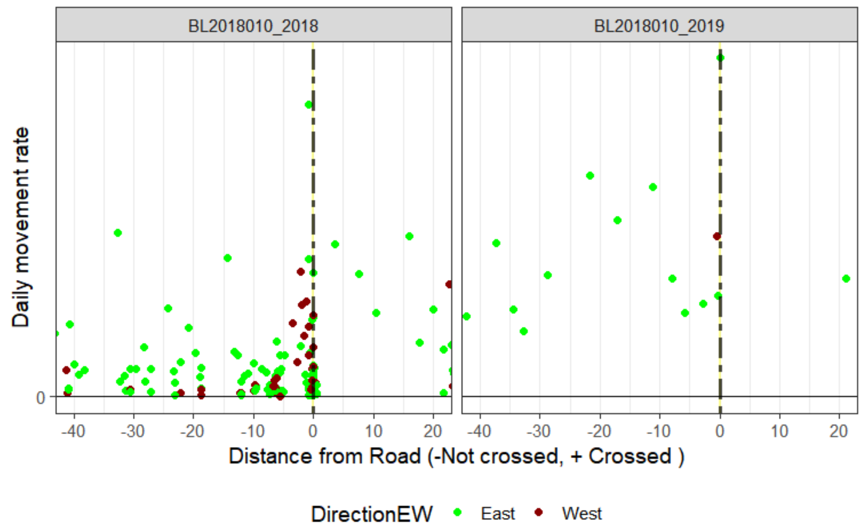

Figure 5. Movement rate as a function of distance from road for BL201810, whose full paths are illustrated in Figure 3 with mine offset (ΔD_{mine}) as a response in Figure 4.

4.3 Regression analyses

4.3.1 Rationale

Variations in individual movement patterns relative to the road were examined using a regression-based approach. Regression techniques allow for an investigation of mixed factors influencing caribou movement patterns relative to road infrastructure, which potentially include habitat, weather, and other temporal covariates. A base model is built initially to account for natural factors that influence caribou movement. Once this base model is built, then the effect of roads on movement is considered. This approach also provided an estimation of the ZOI surrounding mines, roads, or related infrastructure (Boulanger et al 2011).

4.3.2 Regression Covariates

Assessing changes in caribou movement patterns relative to the road, taking into consideration underlying environmental characteristics, requires telemetry points to be attributed with relevant habitat information (Table 1). The metrics in Table 1, which have been used in habitat and ZOI studies (Boulanger et al 2011), tested the effect of topographical, habitat, and seasonal/temporal effects on caribou movements. For example, caribou may slow down in rugged areas or areas of higher elevation in the spring due to snow cover. Habitat, as indexed by ecological land classification (ELC), may cause caribou to move less in areas of high habitat value (Appendix 7.1). Seasonal, yearly and weather effects might also influence caribou movements. Weather covariates were used from weather stations in Baker Lake and the Meadowbank mine, as summarized in Appendix 7.2.

Distance to the AWAR and Whale Tail haul road was calculated for each caribou telemetry location. As the Whale Tail haul road was under construction during the analysis time period, Sentinel Imagery (10 m resolution) was acquired for 3 dates to verify the haul road extent on the landscape. Cloud free imagery were examined for August 2016, June 2017, and June 2018. Telemetry data were partitioned according to these dates, and the distance to the nearest point on either AWAR or Whale Tail haul road, was calculated to ensure the most representative characterization of movement patterns relative to the road.

The location and time of road crossing was estimated by interpolating the location of successive caribou points on either side of the road. Using this approach allowed an estimate of the location of crossing (assuming a straight path between the 2 points) as well as the time of crossing (assuming a constant movement rate between the 2 points). The fix rate for 2015-2018 was 4 hours and therefore the assumption of a linear path and constant movement rate was reasonable, given the relatively short duration between fixes. For deflector caribou that did not cross the road, the average of date and time of the last location west and first location east of the road was used as the crossing date and time. Because the fix interval was 4 hours (for 2015-8) the time and date and time of crossing was always 4 hours or less than the closest location east or west of the road. Earlier years (2011-2) had daily fix intervals and therefore crossing locations were less precise. As discussed later, the primary focus of detailed analyses was 2018-9 which had 4 hour fix intervals.

Table 1. Summary of covariates included in the regression model.

Covariate	Description	Rationale
Habitat		
Elevation	Elevation from DEM	Caribou movement change with elevation
TRI	Terrain ruggedness index	Caribou reduce movements in rugged terrain
Distance to Lake	Distance to nearest shoreline	Lakes will restrict movements if caribou avoid them
ELC	Ecological land classification	Kivalliq Ecological Land Classification (Appendix 1), Pooled to Wet/ice, Shrub, Tundra, and Other
Caribou or sampling effects		
Capture year	Caribou captured > 30 km from road	Caribou captured year of study will show different movements relative to road (Caribou captured <30 km from road not used for the year of capture)
Herd		Herds may interact differently with road given different migration paths
FixRate	Interval between fix (4-24 hours)	Fix interval may affect estimated movement rate
Temporal effects		
JUL	Julian day of year	Seasonality
Year	Year	Travel conditions vary yearly
YearP15	Years prior to 2015 pooled	Less data prior to 2016 so years pooled
YearP16	Years prior to 2016 pooled	Less data prior to 2015 so years pooled
Weather effects		
TempMax	Meadowbank	Weather might affect rate of travel
TempAve	Meadowbank	
Wind gust speed	Baker Lake	
Precipitation	Baker Lake	
Snowfall	Snowfall (Baker Lake)	
Snowonground	Snow on ground at Baker Lake	Ground conditions may reduce rate of travel
Mine effects		
Distance from roads		
Nearest road		AWAR, Meadowbank/Vault and Whale Tail
EW		Road side: not crossed (East) vs West (crossed)
CrosserType	Crosser or deflector	Caribou that come within 5 km of road but never cross the road instead moving around it to the north or south.
Road closure		Available for 2017-9

A complete data set of traffic volume on the Meadowbank AWAR road, or related human use data for the road, was not available for the analysis. Traffic data for 2014-2016 were provided as excel workbooks summarizing monthly traffic volumes for the AWAR road and Meadowbank mine sites, though coding inconsistencies created large gaps in the data rendering it unusable. Traffic data were provided with the following attributes: Depart Time, From, To, Arrival Time, Total time, Vehicle Type, and Date. To and From information, was provided as non-standardized acronyms referring to unknown locations for the AWAR, mine, and Baker Lake areas. Without standardized and explicit "To" and "From" information and vehicle identification codes, traffic volumes could not be reliably related to the road and caribou movements. Traffic data for 2017 -2019 are unavailable.

Road closure data was available for 2017-2019 and was summarized as part of analyses but not modelled directly given that accompanying traffic volume and type data was not available. As discussed later, road closure could be considered further in unison with traffic volume and type data in future analyses. It is also important to note that during road closures, "essential traffic" was allowed through periodically as were spotting trucks, used to identify potential caribou approach. Information on the size, location, and frequency of this "essential traffic" was not available for this analysis.

4.3.3 *Regression analyses*

Initially, a baseline caribou biology model was developed to determine if landscape, biological, and habitat features influenced the movement of caribou relative to the mine and roads (Table 1). Once the baseline caribou biology models were developed, the impact of disturbance was assessed. The primary predictor variable in this case was distance from mine (Table 1), which is the closest distance to the Meadowbank footprint, or the AWAR and Whale tail roads. Segmented regression, as incorporated in the *segmented* package (Muggeo 2003;2008) in the program R, was used to assess if change in daily distance from the mine road (ΔD_{mine}), changed with distance from mine/road at an estimated cut-point (threshold) distance. Segmented regression tests whether ΔD_{mine} changes as a function of distance from the road, and at what distance the change becomes negligible (Boulanger et al. 2012). More exactly, if the road is affecting ΔD_{mine}, it would be expected that ΔD_{mine} would be lower near the road (if caribou movement is being restricted by the road) in comparison to levels observed in paths further from the road prior to road crossing (Figure 3). Once the road is crossed, it might also be possible that movements were restricted through gregarious behavior, where the downstream crossers of a group of caribou are either waiting for others in their group to cross, or, with no additional caribou to wait for, moving away from the road at a quicker rate. In addition, caribou may increase movement rates after crossing the road to make up for delays in migration due to the road, or in response to predators that could be using the road as an accumulation point of prey. In this context, the road possibly had a ZOI prior to crossing and after crossing, which was tested for in the analysis (for years in which crossing occurred).

We note that segmented regression tests the exact zone of influence relationship (Figure 6), and statistically detects the threshold distance at which effects become negligible compared to background levels. Confidence limits are then generated for both the zone of influence as well as the magnitude of zone of influence, which is the slope term up to the estimated zone of influence. If a zone of influence is not detected or is weak, then the slope term for the ZOI curve will not be significant and/or the confidence limits of the ZOI estimate will overlap 0. The advantage of the segmented approach, is that it *does not assume a ZOI,* but instead tests for a ZOI. More exactly, two hypotheses are tested: 1-if a ZOI exists, and 2-what is the relative strength of any existing ZOI. First, a ZOI is estimated with a standard error allowing a hypothesis test to assess if ZOI is different than 0 (H_o ZOI=0 vs. H_a ZOI≠0). Second, the slope term for the ZOI is tested to asses if the gradient in change between the intercept (distance from road=0) to the estimated ZOI is different than 0 (H_o β_{zoi}=0 vs. H_a β_{zoi}≠0). In both cases, the null hypothesis assumes that ZOI and β_{zoi} is 0, meaning that a ZOI is not present and the structures are not influencing caribou movements. If there is a large enough ZOI effect size, then the null hypothesis of 0 ZOI and $\beta_{zoi} = 0$ is rejected in a similar fashion to any regression analysis.

Other approaches to estimate ZOI, such as regular polynomial regression, or comparisons of metrics at binned distance from road intervals, do not provide a model-based framework to test for an exact threshold distance. Published studies of caribou disturbance (Boulanger et al. 2012, Johnson and Russell 2014), and simulation/literature review studies, further support the use of segmented regression for detecting thresholds in ecology (Ficetola and Denoel 2009).

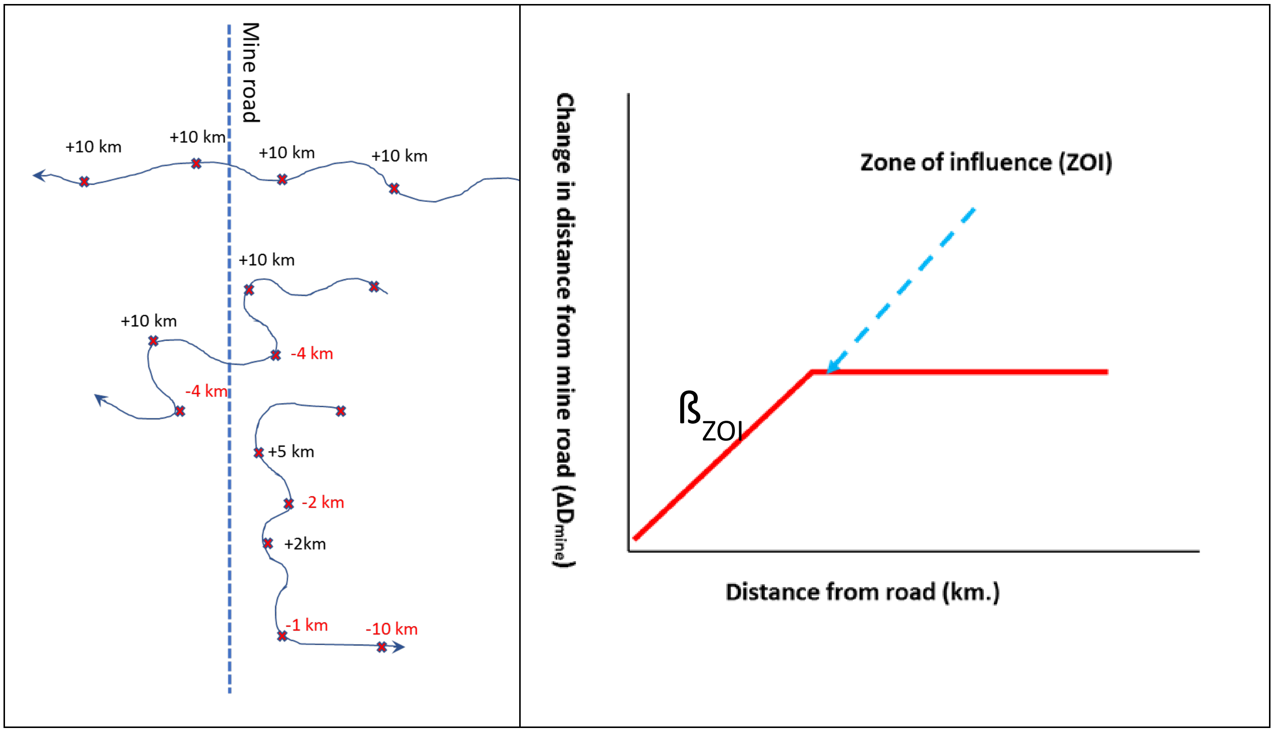

Figure 6. An illustration of the change in daily distance from mine variable (ΔD_{mine}) for 3 hypothetical paths (left), and the hypothesized relationship between distance from mine and (ΔD_{mine}) (right). If caribou move across the road with minimal interference, then ΔD_{mine} should not be influenced by distance from mine with random variation in levels of ΔD_{mine} (upper path). If the mine impedes movement then ΔD_{mine} will be reduced or become negative (red ΔD_{mine} numbers in figure; meaning they moved away from the mine road) prior to crossing (lower path). Estimated ZOI is quantified where variation in ΔD_{mine} is not discernible from random variation.

An assumption of the segmented ZOI approach is that there is a linear slope up the ZOI and no directional trends in ΔD_{mine} after the estimated ZOI. In the context of this analysis, this means that caribou are showing consistent ΔD_{mine} patterns within the ZOI that can be quantified using a linear model. In this case we would expect random ΔD_{mine} patterns outside the ZOI reflecting the natural baseline variation in ΔD_{mine} to be present. We fit smoothed lines to yearly data to allow a partial test of this assumption, and to allow a comparative estimate of approximate ZOI where the smoothed lines asymptote. The smoothed lines used a locally weighted regression (LOESS) method incorporated as part of the *ggplot2* package (Wickham 2009).

The support of baseline caribou biology models and ZOI models were evaluated using information from theoretic model selection methods (Burnham and Anderson 1998). The model with the lowest AIC_c score was considered the most parsimonious, thus minimizing estimate bias and optimizing precision. The difference in AIC_c values between the most supported model and other models (ΔAIC_c), was also used to evaluate the fit of models when their AIC_c scores were close. In general, any model with a ΔAIC_c score of less than 2 was worthy of consideration. Slope parameter estimates and ZOI estimates from the most supported models were further evaluated in terms of confidence interval and overall parameter significance.

One potential issue with the analysis was autocorrelation of measurements from successive daily locations of individual caribou. To confront this issue, confidence limits and parameter significance were evaluated using a generalized estimating equation model (Koper and Manseau 2009) which modelled autocorrelation of successive locations from individual caribou. In addition, the sample size used for model selection calculation was the number of caribou in the analysis rather than the number of locations. An exchangeable correlation matrix was used in the GEE model.

4.4 Estimation of factors affecting delay in crossing

One application of the zone of influence was to estimate the delay in crossing due to a ZOI. A ZOI implies that caribou movements between the estimated ZOI and the mine road are potentially affected by the mine. If the ZOI did not exist, then it would be expected that movement rates relative to the mine road prior to the ZOI would be similar up to when the caribou crossed the road. To estimate time of crossing in the absence of a ZOI, a regression analysis was conducted where the trend in distance from the road was used to estimate the date when the road would be encountered using only the data for distances before the estimated ZOI. For this analysis, the response variable is the date/time for a caribou location, and the primary predictor variable is distance from road. Using this approach, the y-intercept, when distance to road=0, becomes the estimated date of crossing. Movement covariates from the base ZOI model were also considered in this analysis. A random slope and intercepts model (Milliken and Johnson 2002), with individual yearly caribou as the sample unit, was used, allowing for unique estimates of road crossing at distance from road=0 for each caribou. Predicted date of road crossing from the regression models with no ZOI was compared to actual crossing dates of individual caribou to estimate delays.

4.5 Exploration of closure of roads and their effect on the probability of crossing

Road closure is one potential tool to reduce delays in road crossing. It is likely that the influence of intermittent road closures on movements, occurs at distances within sight, sound or smell of the road and/or, associated traffic. In addition, road closures varied, occurring on an hourly or daily basis. For this reason, we estimated probability of road crossing as a function of the distance of each successive caribou location from the road. We assessed if this relationship was influenced by road closure events by modelling an interaction term of distance from road X road closure. As the caribou included in the analysis usually only crossed the road once, the data structure was most easily modelled using conditional logistic regression similar to a case-control or survival analysis (Hosmer and Lemeshow 2000). We therefore used conditional logistic regression with each caribou defined as a stratum, allowing for unique relationships for each caribou-year combination. A GEE robust standard error estimator, which was robust to autocorrelation of successive fixes from each caribou, was used (Koper and Manseau 2009). Road type and other environmental covariates that might affect caribou movement, as identified in the zone of influence analysis, were considered as part of the modelling process.

Analyses were conducted using the *segmented* (Muggeo 2008;2016), *geepack* (Yan 2002), survival (Therneau 2020), *AICcmodavg* (Mazerolle 2016), and the *nlme* package in the *R* (R Development Core Team 2009) statistical package. Results were plotted to graphically explore model results using the *ggplot2* (Wickham 2009) R package with additional mapping in the QGIS package (QGIS Foundation 2015).

4.6 Biased-Correlated Random Walk

A biased correlated random walk analysis was used to estimate delays in migration due to road crossing. This approach, which is independent of the ZOI method, allowed a secondary cross-validation of the ZOI analysis-based estimates of delay.

4.6.1 Variation in individual movement patterns

We employed a biased-correlated random walk (BCRW) approach to examine the effect of the road on individual movement patterns in the spring only. A BCRW model based on the methods outlined in Wilson et al. 2016 was applied using parameters suggested by Bartoń et al. (2009). BCRW methods are primarily used to simulate data (i.e. predicted patterns) that can be compared to recorded data (i.e. observed patterns). Simulated trajectories represent predicted movement patterns under the assumption that the road has no effect on caribou movements occurring in or near-road areas. The simulated vs. observed comparison identifies discrepancies between predicted and recorded patterns, and therefore makes it possible to statistically test whether crossing time changes for caribou crossing the road while migrating.

The BCRW relied on expected patterns derived from empirical step length (distance travelled between reporting periods), and absolute angle (direction of travel) distributions calculated from observed data. Expected patterns were compared to observed trajectories to quantify any delays in migration associated with caribou-road interactions. Specifically, the BCRW model identified caribou whose movement trajectories either (a) were delayed, or (b) did not change, when approaching or crossing the road infrastructure.

4.6.2 Data screening

To ensure that the BCRW analysis was an appropriate cross-validation tool, the same collars included in the regression analysis were included in the BCRW. However, due to the difference in how the two approaches determine delays in migration, the data screening process to identify the telemetry locations to be included in the analysis differed. Each caribou movement trajectory was visually inspected to identify: migration start date, migration end date, first location within 20 kilometres of the road, last location within 20 kilometres of the road, road crossing location, and migration end location. These key trajectory locations were used to construct the BCRW models for each road crossing event. Two collars included in the regression analysis were excluded from the BCRW, as they had data gaps that made the identification of the key trajectory locations impossible.

For a similar BCRW analysis, Wilson et al. 2016 used an analysis distance of 15 kilometres based on existing literature on caribou response to human-related disturbance (Boulanger et al. 2012). We increased our threshold to 20 kilometres to provide a more conservative estimate for the simulated near-road patterns.

The individual migration end dates were defined either by a sustained change in pattern from long range movements to restricted seasonal range movements, or by the first location within the official Lorillard core calving area (Campbell et al. 2014). Individual migration end dates were identified for each dataset based on movement rate, rather than using the official subpopulation seasonal dates, specifically to account for individual inter-annual variation in migration periods. Applying the official seasonal date ranges (Nagy 2011) resulted in some truncated migration pathways, while others included short, tortuous movements associated with calving or winter range use.

To characterize the movement patterns for each migration pathway, step length and absolute angle were calculated for each segment in the observed trajectory. Step length is defined as the Euclidean distance between successive telemetry fixes and can be used to calculate movement rate when divided by the time elapsed between fixes. Absolute angle is described as the angle formed between the x-direction and the step (Figure 7). Absolute angle can be used to determine movement direction and, when examined along the entire trajectory, can be used to quantify overall directionality. For trajectories that demonstrate a high degree of directionality, absolute angles are relatively consistent, whereas more meandering trajectories are made up of a wider range of angles. The mean resultant length (rho), hereafter referred to as the directionality coefficient, is the parameter in the BCRW model that is used to capture this directionality and controls the directional persistence of the simulated pathway. Coefficient values close to zero represent weak directional persistence and generate a clustered trajectory; whereas coefficient values close to one (1), represent a strong directional persistence and generate a straight trajectory more typical of migratory behaviour.

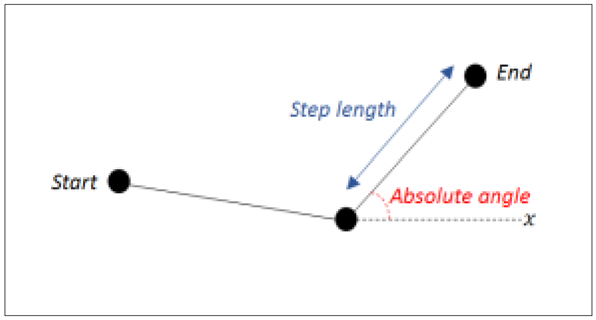

Figure 7. Description of step length and absolute angle movement calculated for each segment of a caribou's path. The derived values were used to identify both delayed and normal road crossers. Step length is described as the distance between two successive telemetry point locations. Longer step lengths indicate faster movement, while shorter step lengths illustrate slower movement patterns. The absolute angle is the angle between the x-direction and the step. Smaller angles are characteristic of clustered movements, while larger angles mean the path follows a straight trajectory.

4.6.3 Biased-Correlated Random Walk

Step length and absolute angle distributions were generated from the observed trajectories for each animal trajectory (Barton et al. 2009). Subsequently, for each individual, 500 trajectories were simulated using the associated step length and absolute angle distributions. From the 500 simulated pathways, a null distribution of crossing times, measured in days, was generated by determining the number of days between the first simulated location within the 20-kilometre threshold distance, and when the individual crossed the road. Individuals were designated as 'delayed crossers' if the observed crossing time was greater than the mean expected crossing time. All movement metrics were calculated using the *adehabitatLT* package in R (Calenge 2015).

5.0 RESULTS

5.1 Summary of data used in the analyses

5.1.1 Herd movements relative to road

Herds displayed unique movements relative to the roads with predominantly the Lorillard, and secondarily the Wager Bay subpopulations encountering the roads during most seasons. The Ahiak occasionally encountering the road, and the Beverly rarely encountering the road. The general path of the Wager Bay herd made it more likely to encounter the Whale Tail road whereas the Lorillard herd encountered the AWAR and the Whale Tail road (Figure 8).

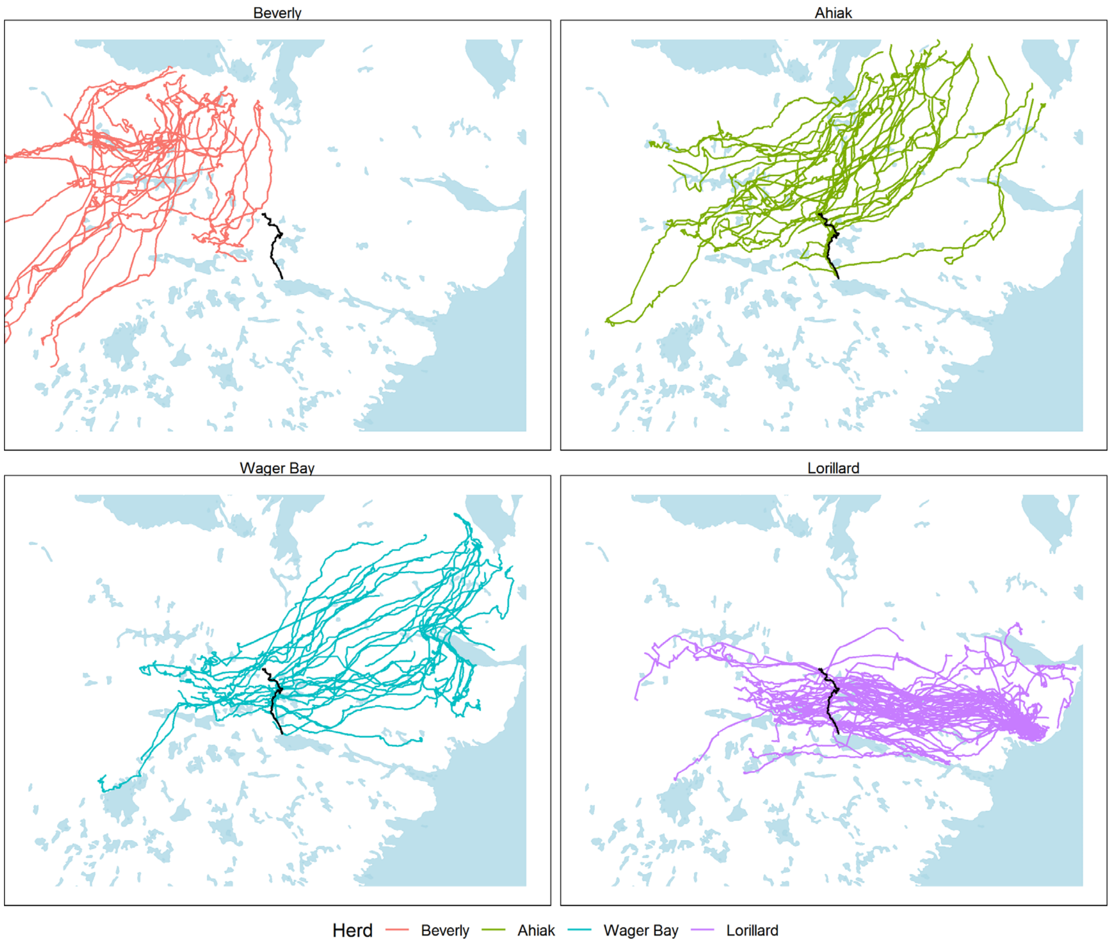

Figure 8. Spring migration paths of 4 caribou herds relative to the Meadowbank mine and roads.

5.1.2 *Data screening summary*

Data screening resulted in yearly sample sizes range from 7 to 13 caribou (Table 2), with the majority of caribou coming from the Lorillard herd. The majority of caribou mainly interacted (as indicated by proportion locations within 15 km of a given road) with the AWAR road for most years except for 2019 when 49% of interactions were with the Whale Tail road (which was only present after 2016). A full summary of data screening methods is given in Appendix 7.3. The most recent collaring program occurred in April 2018, at which time 25 caribou were collared. To ensure the collaring program did not bias caribou behaviour along the road, 2018 caribou collared within 20 km of the road were removed from the analysis.

Fix interval for collars was 24 hours for 2011 and 2012, 6 to 24 hours for 2013, and 4 hours from 2015 to 2019.

Table 2. Sample sizes of collared caribou used in the spring migration analyses. See Appendix 7.3 for more details on sample sizes and data screening methods.

Year	Collars included in analysis					Collars not included in analysis		Proportion locations within 15 km of road		
	Ahiak	Lorillard	Unknown	Wager Bay	Total	Captured < 20 km From road	Locations away from road	AWAR	Vault	Whale Tail
2010	0	0	0	0	0	0	12			
2011	0	7	0	0	7	5	6	0.94	0.06	
2012	0	2	0	0	2	0	9	0.75	0.25	
2013	0	2	1	0	3	0	6	0.96	0.04	
2014	0	0	0	0	0	0	5			
2015	2	3	0	0	5	2	3	0.85	0.15	
2016	0	4	0	1	5	9	8	0.54	0.27	0.19
2017	0	0	0	0	0	0	14			
2018	2	8	1	2	13	21	2	0.82	0.04	0.14
2019	2	3	0	6	11	0	11	0.50	0.01	0.49
Totals	6	29	1	9	45	37	76			

Yearly paths of caribou demonstrate variability in movement relative to the roads which was dependent on yearly sample sizes of caribou as well as the caribou herd (Figure 9). Prior to 2017, caribou tended to move northward when the AWAR road was encountered, with some deflections to the north of the main Meadowbank mine and Vault roads. The Whale Tail road was mostly in place in 2018 though construction of the road occurred in years prior. There were no trajectories near any roads in 2017 since no caribou migrated past the AWAR road in the fall of 2016.

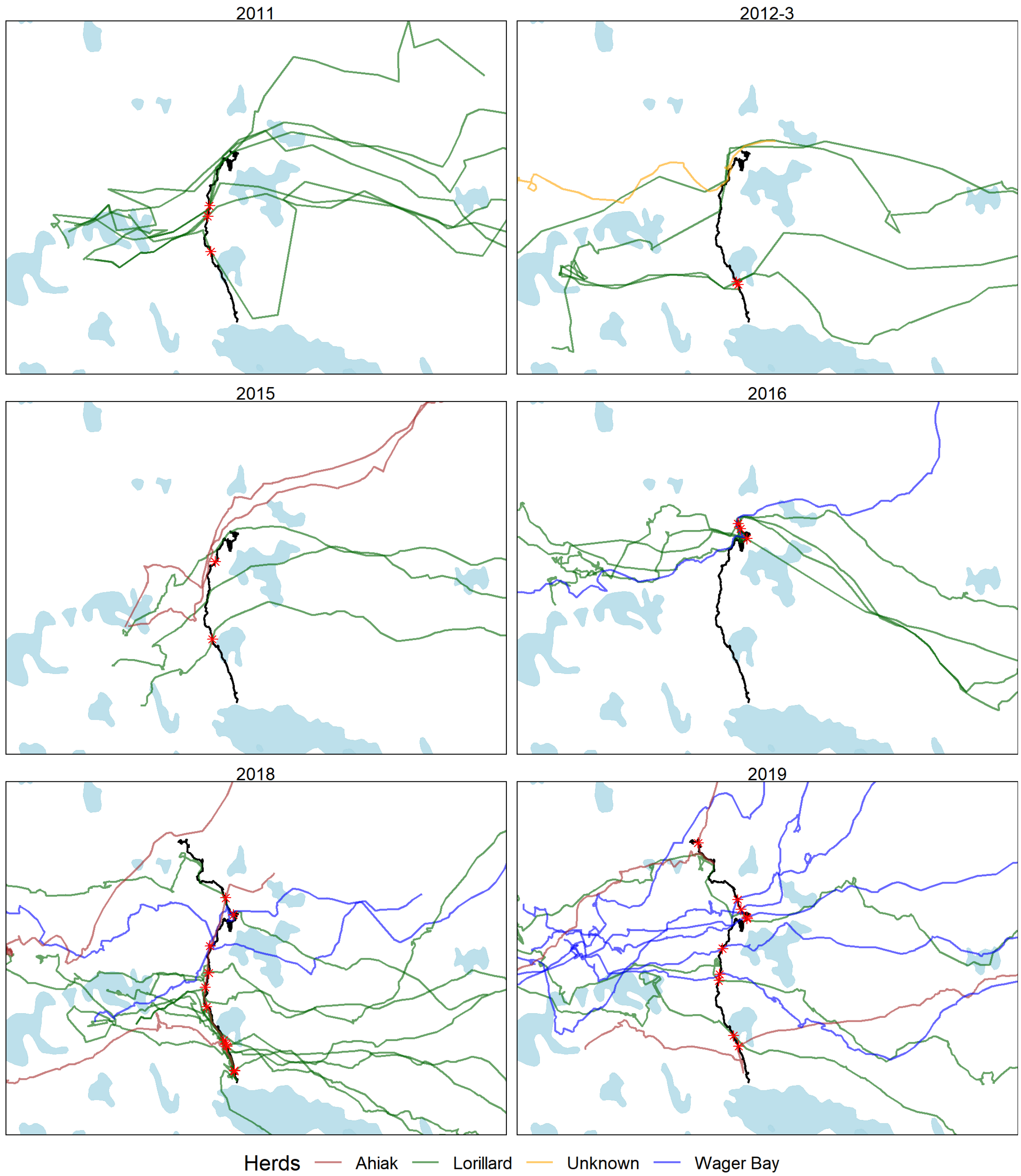

Figure 9. Paths of caribou relative to the Meadowbank mine road for spring migration. The progression of construction of the Whale tail road is illustrated with most expansion occurring between 2016 and 2017.

A closeup map of trajectories demonstrates that behaviour relative to the road changed between 2011-2016 and 2018-2019 (Figure 10). Namely, prior to the full completion of the Whale Tail road in 2018, 55% (12 of 22 caribou) of collared caribou that encountered the road deflected around the north end of the AWAR and mine/Vault roads. A deflector is defined as a caribou that came within 5 km of the road but never crossed the road instead moving along the road finally crossing north or south of the road start or endpoints. Upon building of the Whale Tail road (2018-2019), caribou that travelled north past the Meadowbank mine, crossed the Whale Tail road resulting in a lower proportion (14%: 3 of 23 collared caribou) of deflectors. Logistic regression results indicated that the difference in proportion of caribou crossing vs deflecting along both the Whale Tail and AWAR roads was significant between the periods of 2011-2016 (prior to Whale Tail Road) and 2018-2019 (β=2.12, SE=0.75, Z=-2.83,p=0.0046). The odds of a caribou crossing one of the Meadowbank roads versus deflecting) was 8.3 times greater (CI=2.1-43.4) in 2018-2019 versus 2011-2016 presumably due to the presence of the Whale Tail road.

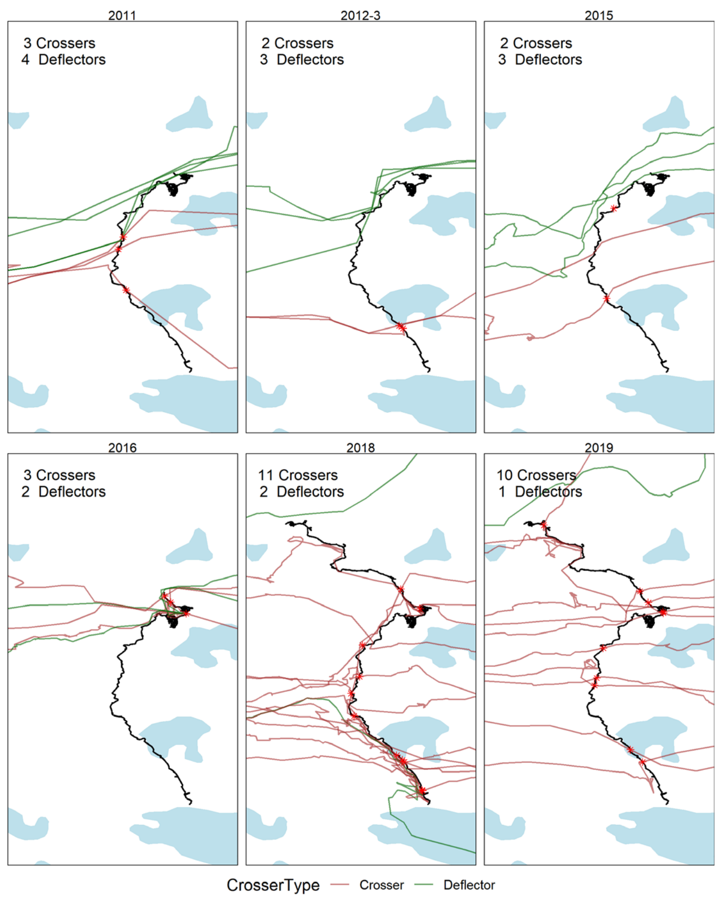

Figure 10. A close up view of paths of caribou relative to the Meadowbank mine road for spring migration with crosser and deflector caribou identified and frequencies of each crosser type summarized by year. A red star indicates crossing locations for crosser caribou.

5.1.3 Movement trajectories

Spring migration data from 2011-2019 was used for the analysis (Figure 11). Yearly data was pooled, however, year-specific values of ΔD_{mine} were considered in cases where migration rates varied between years. A plot of date by distance from mine road revealed a relatively constant rate of travel for most years as indicated by the similar angled trajectories in the data. The timing of migration relative to the road varied yearly with crossing occurring earlier in 2019 compared to 2018. At approximately 10-20 km from the road, travel rates relative to the road decreased for some caribou as indicated by reduced slope in trajectories along the road, and westerly directions of trajectories (away from the road as indicated by red points) in the vicinity of the road. A vertical trajectory indicated movement parallel to the road. Once the road was crossed, the relative rate of travel became similar to that observed for caribou approaching the road from greater than 20 km west of the road. The direction and rate of travel was delayed after crossing the road for a few caribou as indicated by red dots or a slight vertical offset between the trajectory both before and after the road.

Movements away from the road and counter to the direction of migration (red dots in Figure 11), that occurred across the range of distances, were considered as to potential mechanisms that may have influenced rates of movement, other then the road and associated affects. These other potential mechanisms include weather and geographic variables. For this reason, a base model was used to assess other factors influencing movement before zone of influence was considered.

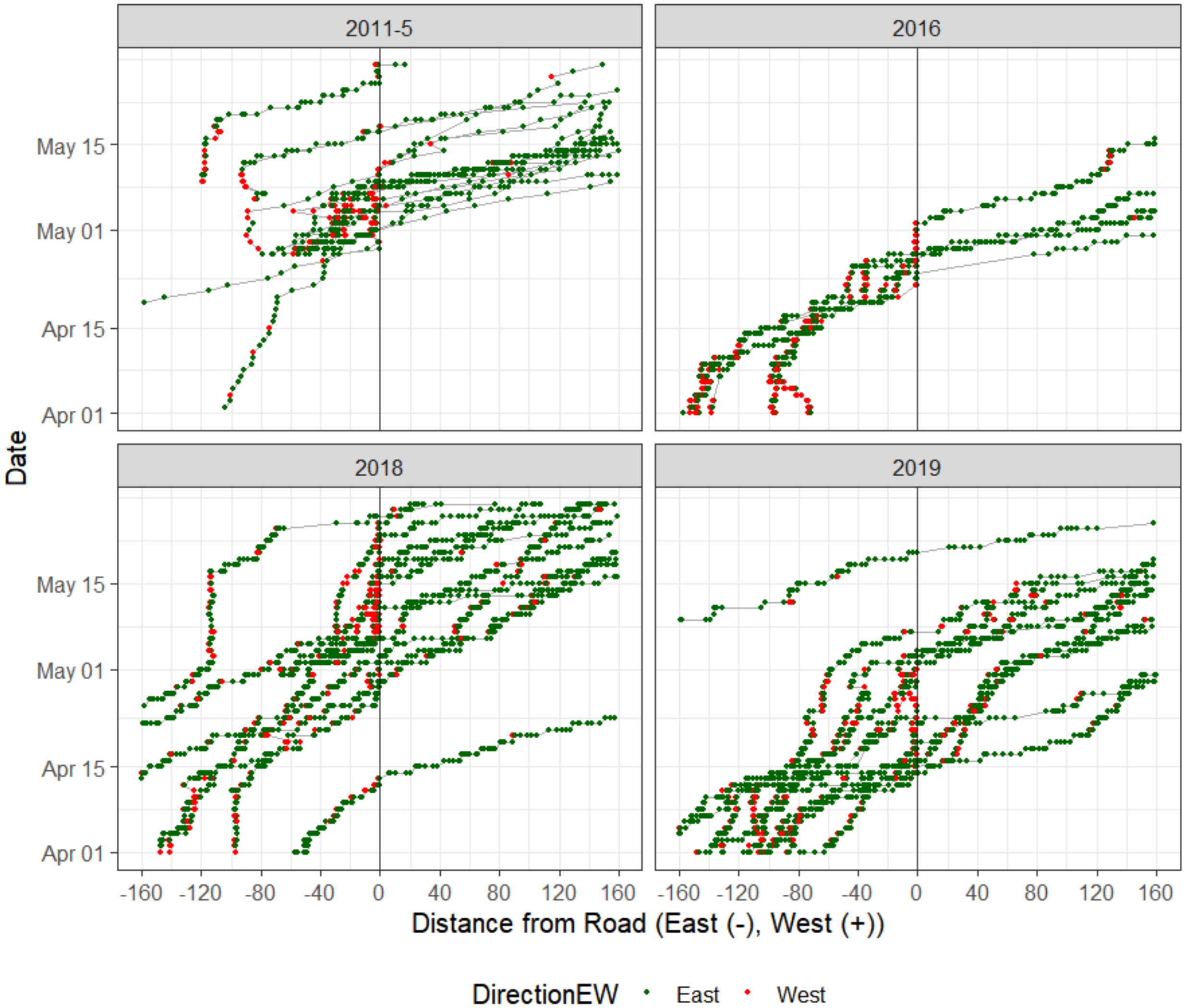

Figure 11. The movement trajectories of individual caribou points relative to the Meadowbank road (at 0 distance) by date for spring migrations from 2016-2019. Points to the left of the center line are for caribou before they crossed the road, and points to the right are after they crossed the road. Red points indicate a westward movement (counter to the direction of migration) and green points indicate eastward movement (consistent with the direction of migration). Vertical trajectories of any one collar indicate movement parallel to the road.

5.2 Regression and ZOI analyses

Histograms generated from the individual caribou movements suggested that the overall distribution of ΔD_{mine} was well described by a normal distribution. As an initial step, base caribou biology covariate terms were considered (Table 3 and Appendix 7.4) with year (pooled 2011-2015, 2016, 2018, and 2019), maximum daily temperature at Meadowbank, Ice, ecological land classification (ELC) habitat data, and whether a caribou was east or west of the road, as the most supported base model.

The base model covariates were then considered with ZOI terms. Zones of influence terms considered included a ZOI prior to crossing (Model 9:NC: the west side of the road), and after crossing (C: the east side of the road). In addition, unique zones of influence for different roads (Model 8: $NC_{roads:}$Whale Tail, Vault, AWAR), live capture in 2018 (Model 7: (NC_{18cap+} $NC_{18nocap}$)) and year-specific crossing (Models 1-5: NC_{16}, $NC_{18,}$ and NC_{19}) were modeled. Models with year-specific ZOI's, and ZOI's for 2011-5 were also attempted however models did not converge presumably due to sparse yearly data prior to 2018 (sample sizes of less than 10 caribou per year). Models with unique ZOI based on year of capture (models 6 and 7), roads (model 8) and deflector vs crosser caribou (model 9) were also considered which showed higher support than models without ZOI terms. Of these models, a model with year-specific mean rates for 2018 and 2019 of $\Delta D_{mine,,}$ TempMax, and Ice influencing ΔD_{mine} and different zones of influence for 2018 and 2019 prior to crossing and unique zone of influence after crossing, was most supported (Table 3, model 1).

Table 3. Model selection for the spring migration (2011-2019) regression analysis of daily change in distance from mine. Only models with more support than an intercept model are shown. Akaike Information Criteria (AIC_c), the difference in AIC_c values between the *i*th and most supported model 1 (ΔAIC_c), Akaike weights (w_i), number of parameters (*K*), and log-likelihood (LL) are presented. ZOI terms are abbreviates as prior to crossing (NC) which would be the west side of the road, and crossing (C) which would be the east side of the road. A full listing of models considered is given in Appendix 7.4 with listings of base model covariate names given in Table 1.

No	Base	ZOI	AICc	ΔAICc	K	w_i	LL
1	YearP16+TempMax+ice	$C+NC_{18}+NC_{19}$	50200.0	0.00	11	0.66	-25083.3
2	YearP15+TempMax+ice	$C+NC_{18}+NC_{19}$	50203.2	3.18	12	0.14	-25082.9
3	YearP16+EW+TempMax+ice	$C+NC_{18}+NC_{19}$	50203.8	3.76	12	0.10	-25083.2
4	YearP16+TempMax+ice+CapYear	$C+NC_{18}+NC_{19}$	50203.9	3.88	12	0.10	-25083.3
5	YearP15+TempMax+ice	$C+NC_{16}+NC_{18}+NC_{19}$	50209.9	9.93	14	0.00	-25082.0
6	YearP16+TempMax+ice	$C+NC_{18cap+}\ NC_{18nocap}+NC_{19}$	50236.6	36.6	12	0.00	-25097.5
7	YearP15+TempMax+ice	$C+NC_{Capyear}+NC$	50280.0	48.91	12	0.00	-25121.3
8	YearP15+TempMax+ice	$C+NC_{Roads(AWAR/WT)}$	50280.0	79.94	12	0.00	-25121.3
9	YearP15+TempMax+ice	$C+NC_{Crosser}+NC_{Deflector}$	50283.1	83.12	12	0.00	-25122.9
10	YearP15+TempMax+ice	C+NC	50285.5	85.47	11	0.00	-25126.0
11	YearP16	$C+NC_{18}+NC_{19}$	50304.4	104.35	14	0.00	-25129.2
12	YearP15+EW+TempMax+ice		50357.8	157.75	8	0.00	-25168.9
13	YearP15+EW+ELC		50379.9	179.90	7	0.00	-25181.5
14	YearP15+EW+ice		50519.8	319.81	11	0.00	-25245.0
15	YearP15+EW+lake_dist		50525.9	325.84	7	0.00	-25254.5
16	YearP15+TempMax+ice	$C+NC_{Herd}$	50531.2	331.17	7	0.00	-25255.6
17	YearP15+EW		50546.7	346.68	7	0.00	-25264.9
18	EW		50551.7	351.74	6	0.00	-25268.8
19	YearP15+TempMax+ice	C=NC	50601.9	401.90	8	0.00	-25289.5
20	constant		51363.8	1163.78	2	0.00	-25679.8

Evaluation of parameters for model 1 suggest that all terms including β_{zoi} and ZOI terms were significant (Table 4). The positive value of the TempMax terms suggest movement rates increased when temperature was warmer. In addition, movement rates increased for locations with an ice ELC class. These locations were usually not in larger lakes, which were likely avoided, but instead in other smaller water areas that were frozen during the spring (Figure 9 and Figure 27 in Appendix 7.1). The β_{ZOI} terms indicate that ΔD_{mine} increases after crossing on the East side of the road but was reduced prior to crossing on the west side of the road in 2018 and 2019. In all cases these slope terms are significant.

Table 4. GEE model estimates of regression parameters for model 1 (Table 3) including zone of influence slope terms.

Parameter	Beta	Std. Err.	Z	P-value
<u>Base terms</u>				
(Intercept)	27.58	2.58	114.24	0.0000
Year (2018)	-4.54	0.87	27.07	0.0000
Year (2019)	-5.10	1.01	25.59	0.0000
TempMax	0.26	0.04	37.10	0.0000
Ice	2.56	0.67	14.42	0.0001
<u>β_{ZOI} terms</u>				
East side of road (crossed): all years	2.97	1.10	7.26	0.0070
West side of road (not crossed): 2018	-0.26	0.10	6.93	0.0085
West side of road (not crossed): 2019	-0.36	0.16	5.05	0.0246

ZOI estimates were significant with a ZOI of 2.9 km after crossing and 16.3-17.2 km in 2018 (Table 5). ZOI was not tested prior to 2018 given low support of models with terms for these years.

Table 5. Estimates of zone of influence from model 1 (Tables 3 and 4).

Parameter (Crossing orientation)	ZOI	Std. Error	Wald Z	P-value	CI low	CI high
East side of road (crossed): all years	2.97	1.13	-2.62	0.0087	0.75	5.18
West side of road (not crossed): 2018	17.21	5.47	-3.15	0.0017	6.49	27.92
West side of road (not crossed): 2019	16.29	5.97	-2.73	0.0064	4.58	28.00

Plots of yearly model predictions and ΔD_{mine} observations show a higher density of ΔD_{mine} observations of lower value (or less than 0 indicating net movement west away from the road) prior to crossing, with the estimated ZOI's shown for each year (Figure 12). The ZOI on the east side of the road (at 2.97 km) is characterized by a lower number of west movements, as well as a slightly higher overall rate of travel away from the road once it was crossed. Mine offset terms ΔD_{mine} of less than 0 occur at a distance further then the estimated ZOI in both years, however, they are aggregated within the area of the ZOI to a greater degree than distances beyond the ZOI.

A locally weighted regression line is shown for each of the years as a comparison with estimated ZOI. The lines do not show directional trends beyond the ZOI for 2018 and 2019. The inflection point of the line is very close to the estimated ZOI, further demonstrating the fit of the ZOI curve. Furthermore, the intercept value of smoothed regression (LOESS) lines on the east side of the line (after crossing) occurs at the height of the ZOI curve suggesting a similar change in ΔD_{mine} once the road has been crossed.

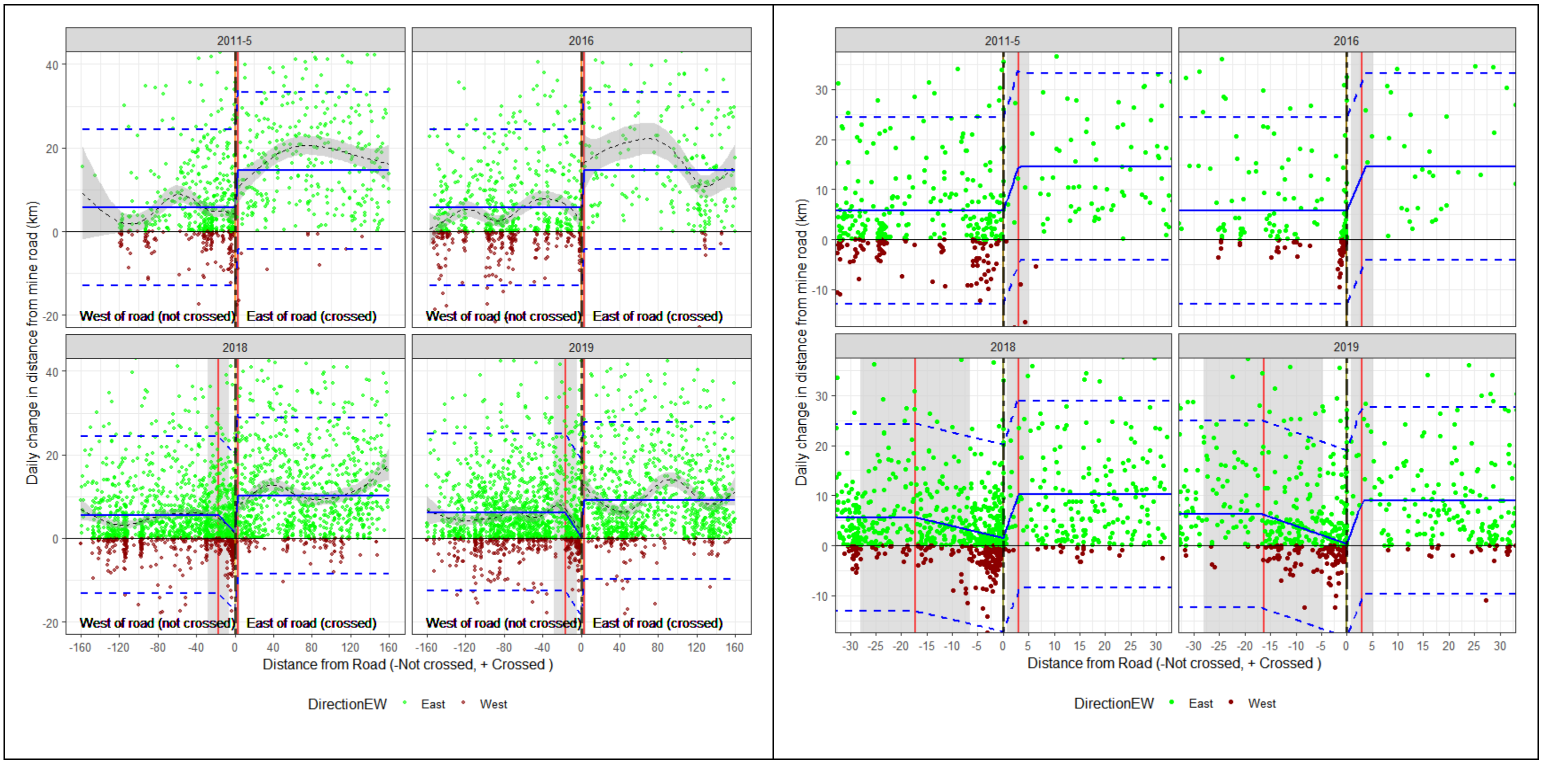

Figure 12. Predictions of a segmented model for spring migration (2016-2019). The left plot shows the full data set and the right plot is zoomed into the zone of influence area. The zones of influence estimates are shown as a red line on either side of the road with confidence limits as shaded regions. Predicted mean ΔD_{mine} are shown as blue lines (confidence intervals as dashed lines). Observed ΔD_{mine} are shown as points which are color-coded based on net direction since last observation. A LOESS fitted line (grey shaded area with hashed line) is shown for comparison purposes.

Significant zones of influence were not detected for 2011-2015 and 2016, however, there is an observed concentration of points around the road prior to crossing in both years. The potential reason for non-significant zones of influence for these years is low sample size of points combined with a higher proportion of caribou that deflected to the north and therefore never directly crossed the road (Figure 10). One of the models considered (Table 3: Model 9) estimated specific ZOI terms for deflectors and crossers. This model was not as supported as the year-specific models but was still more supported than a model without ZOI terms (Model 12). Estimates of zone of influence from this model for crossers (pooled across all years) was 16.7 km (CI=6.2-27.3, Z=3.12,p=0.001) and for deflectors 3.74 (CI=-14.2-21.7,Z=-0.4, p=0.68). The nonsignificance of ZOI terms for deflectors is intuitive in that these caribou will be less delayed by the road given that they never directly cross it but rather, walk around it and/or away from it. Of 22 caribou monitored from 2011-2016, 12 were deflectors and 10 were crossers (Figure 10). In contrast, of 24 caribou monitored in 2018-2019, 3 were deflectors and 19 were crossers which was partially due to the Whale Tail road occurring in the usual area where caribou deflected north of the AWAR road. It is likely that year-specific factors such as traffic volume and closures also influenced ZOI and deflections of caribou. Sample sizes limited the ability to estimate year-specific ZOI's for deflectors and crossers.

5.3 Movement rates relative to ZOI

Observations of net movement rate (distance moved between locations divided by fix interval) for 2018 and 2019 (when a ZOI was evident), demonstrates that the movement rate of caribou relative to the road increases when caribou are moving parallel to the road (Figure 13). The general pattern of movement parallel to the road as a response, is also seen in movement trajectories. This change in movement occurs at the approximate ZOI. These results suggest that parallel movement is the primary response to the road in terms of movement rate. We note that parallel movement to the road results in a decreased ΔDmine rate even if the actual movement of the caribou is increased. We also note that movement away from the road is also evident, forming a secondary response to road effects.

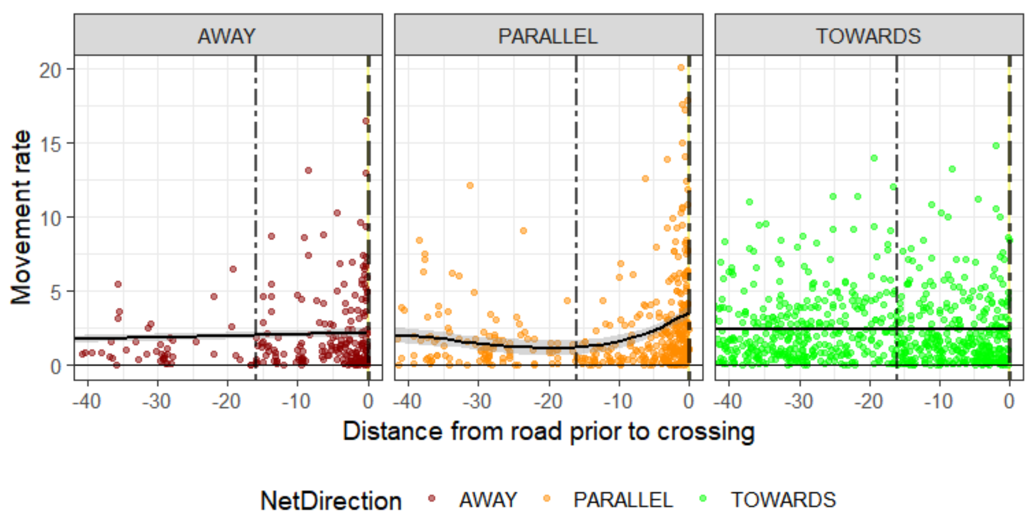

Figure 13. Movement rates relative to the road (heavy hashed line) in 2018 and 2019 as a function of net direction. The average ZOI (16.6 km) is delineated by a light hashed line. A smoothing term is provided to assess directional trends in the data (shaded black line). The parallel direction is based upon the relative angle of the caribou path (relative to the last location). Path segment directions within +/- 27.5 degrees of the road direction were categorized as parallel.

5.4 Estimation of delays in road crossing based on zones of influence

The primary focus of the delay analysis was 2018 and 2019 when ZOI's were estimated, however, the analysis was also run for 2011-2016 where no significant ZOI's were detected. These years were used as a "control" to see how well the method predicted delays when ZOI's were not detected. Data ranging from 40 km to the estimated ZOI were used for the analysis. An average ZOI (16.8) was used for 2011-6. This range maximized sample sizes of points for each caribou given the general data deficiencies encountered in the earlier years.

The general terms from the ZOI model were considered including the *Ice* and *temp max* covariates. Of these the *temp max* covariate was significant (Table 6) suggesting a temperature influence on movements. In addition, year-specific intercepts were modelled to accommodate likely yearly differences in timing of migration. Temperature reduced the expected time of crossing the road as it was positively associated with movement rate. Most of the terms in the model were significant suggesting that the timing of migration varied between years. The yearly terms can be interpreted as the relative mean difference in days when caribou encountered the road each year in comparison to 2011. For example, caribou encountered the road on average 7.10 days later in 2012 compared to 2011.

Table 6. Estimates of fixed effects from random effects analysis of factors affecting timing of road crossing. Individual slopes for the effect of distance from mine roads was modelled as a random effect.

Road Crossing Parameter	Estimate	SE	DF	t-value	p-value
(Intercept)	18023.24	3.49	352	5164.0	0.000
Distance from road	0.15	0.02	352	7.2	0.000
Year-2012	-7.10	7.20	39	-1.0	0.330
Year-2013	15.88	6.20	39	2.6	0.014
Year-2014	-3.32	5.27	39	-0.6	0.532
Year-2015	-12.13	5.28	39	-2.3	0.027
Year-2016	-1.14	4.22	39	-0.3	0.788
Year-2019	-11.01	4.35	39	-2.5	0.015
Temp_Max_MBK	-0.11	0.02	352	-5.3	0.000

The delay in crossing was estimated as the difference between the estimated crossing from the random effects model and the actual crossing date. The results of this analysis are shown for each caribou movement trajectory in Figures 14 and 15. Also shown is the closest road to the caribou trajectory and whether the closest road was open or closed.

A few trends are evident in Figures 14 and 15. First, when delays occurred, the predicted path deviated from the observed trajectory soon after crossing into the ZOI, with parallel movement (vertical path in the movement trajectory) most often occurring. Second, caribou often traversed along more than one road with a general tendency of northward movement from AWAR to Vault/Whale Tail roads. Third, delays often occurred when the road was open to regular traffic (as delineated by the green shading around the road). The topic of delay and road closure is explored further in the next section of this report.

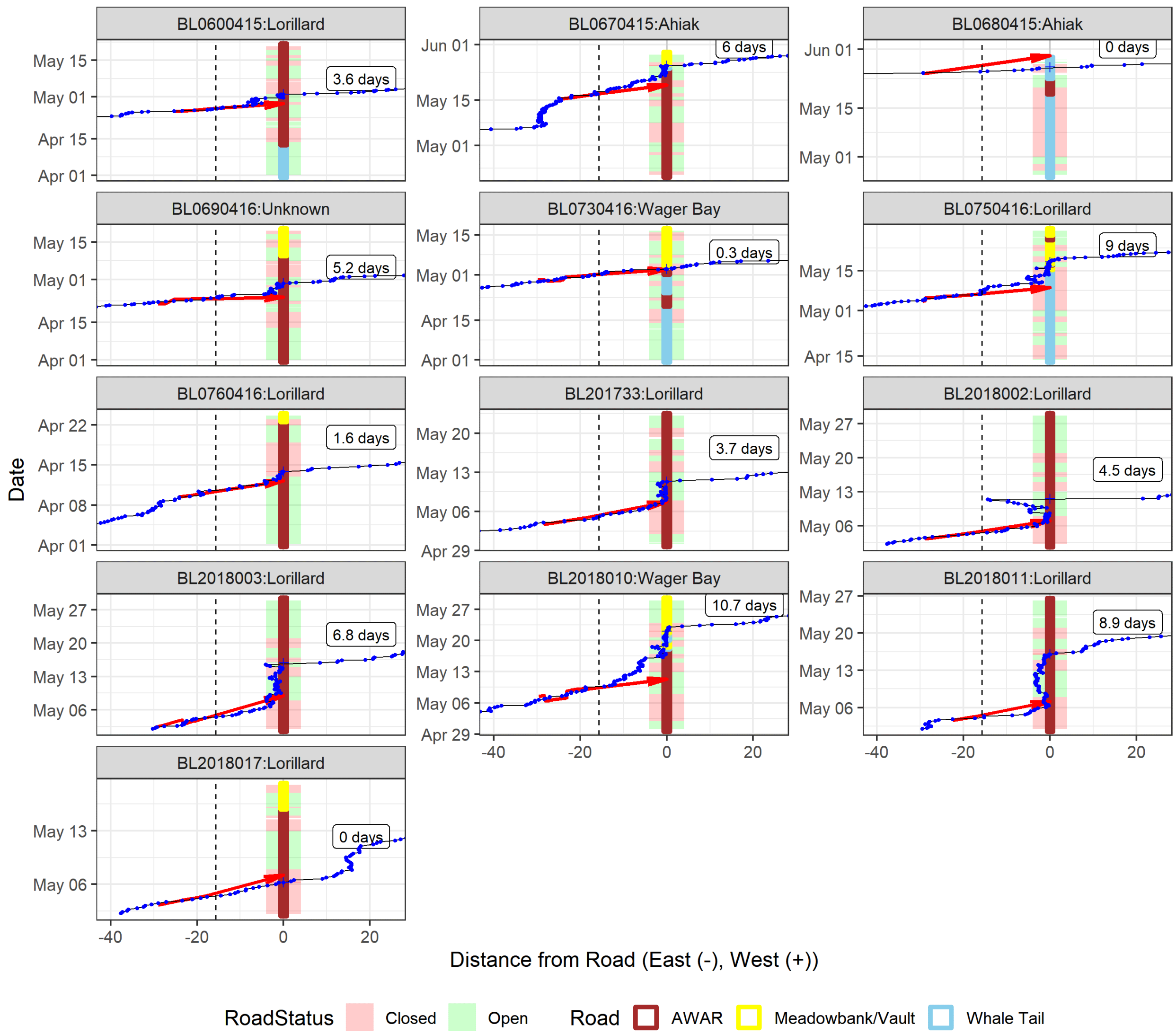

Figure 14. Individual movement trajectories of caribou for 2018 (blue line), with estimated random effects model paths (red bold arrow) using data from beyond the ZOI (black dashed line). Also shown is the nearest road (colored line at intercept (0)) and whether the road was open or closed based on the caribou's closest location to the road (shaded green or red area around intercept). The estimated delay in days is given as a boxed value near each line.

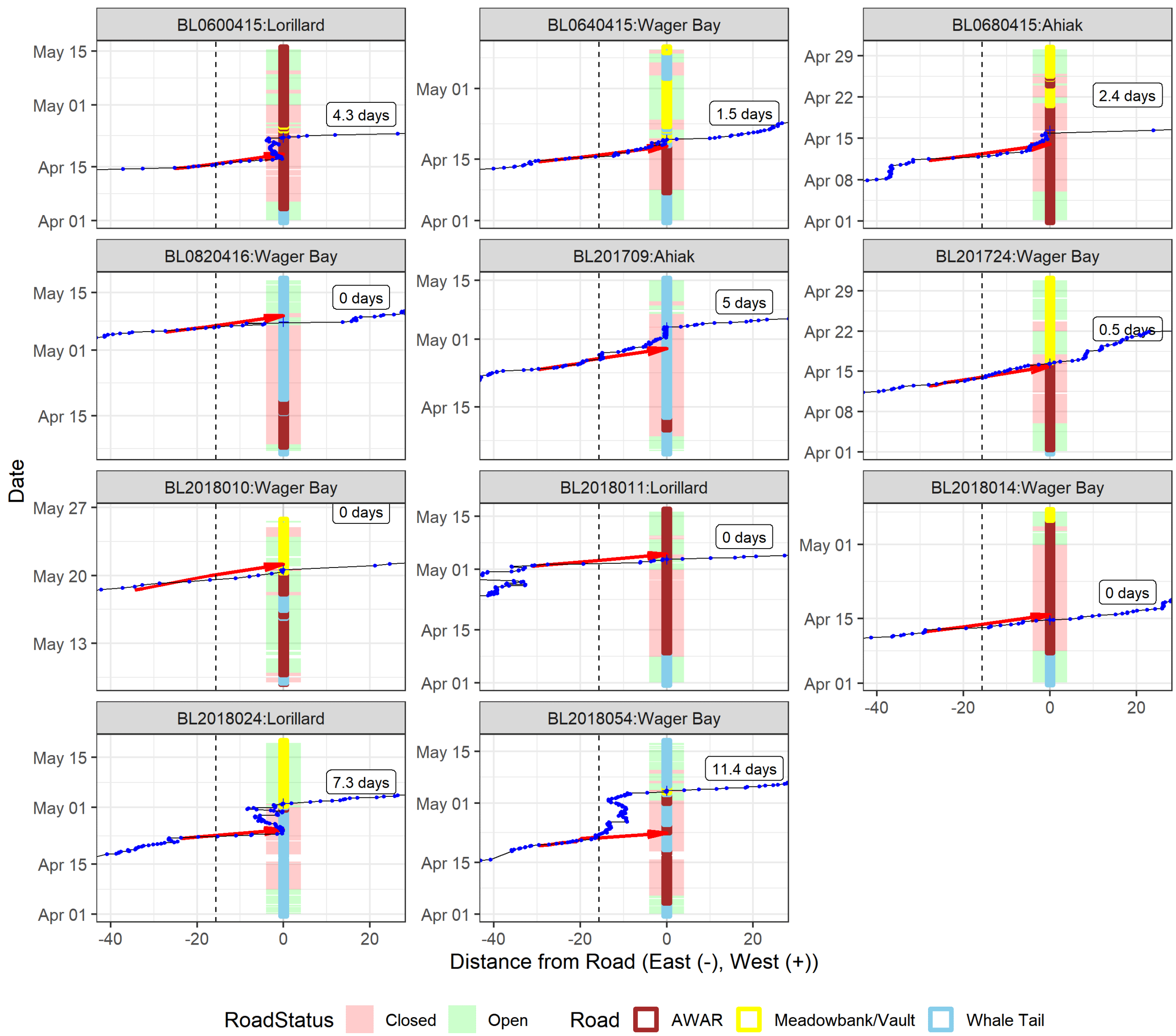

Figure 15. Individual movement trajectories of caribou for 2019 (blue line), with estimated random effects model paths (red arrow) using data from beyond the ZOI (black dashed line). Also shown is the nearest road (colored line at intercept (0)) and whether the road was open or closed based on the caribou's closest location to the road (shaded green or red area around intercept). The estimated delay in days is given as a boxed value near each line.

Estimates of crossing delay were close to 0 up to 2018 (Table 7). When delay was minimal it was possible for the caribou to cross the road sooner than predicted resulting in a negative delay value. This presumably could be due to caribou increasing movements closer to the road as well as the higher proportion of defector caribou in these years. The exposure to roads, as indicated by the proportion of locations closest to each road (pooled) showed that most caribou were most exposed to AWAR except in 2016 and 2019. In 2016, 3 of 5 caribou did not cross but rather deflected above the Vault road area (Figure 8). In 2019, the Wager Bay caribou (that were collared in 2018) traversed across the Whale Tail road area resulting in higher exposure to this road. The increase in migration delay through time is likely due to the differences in road types and traffic volumes between years. Another factor that likely influenced estimates of delay was lower resolution of collar data in 2011 and 2012 when the fix interval was 24 hours. We note that the effect of intermittent road closure was not considered in estimates of delay. This effect is considered in the next section of the report.

Table 7. Estimated delays from random effects model by year. Also given is the number of collared caribou delayed (delay >0) vs the total number of collars used in the analysis. Frequencies of deflectors (Figure 10) are also listed. The proportion locations near each road are also indicated.

Year	Estimated delay in crossing				Collars			Nearest roads to locations within 15km of roads			
	Mean	std	min	max	delayed	Defl-ectors	total	Proportion interacting with AWAR	Proportion Interacting with Mine /Vault	Proportion interacting with Whale Tail	# of fixes w/in ZOI
2011	0.0	1.5	-2.8	1.7	3	4	7	0.94	0.06		18
2012	0.4	2.1	-1.1	1.9	1	2	2	0.75	0.25		8
2013	0.0	2.3	-2.3	2.3	1	1	3	0.96	0.04		26
2015	-1.1	4.1	-5.1	5.7	1	3	5	0.85	0.15		103
2016	1.6	4.4	-2.0	9.2	3	2	5	0.54	0.27	0.19	118
2018	4.3	4.1	-3.3	10.7	11	2	13	0.82	0.04	0.14	527
2019	2.5	4.1	-1.5	11.4	7	1	11	0.50	0.01	0.49	314

A plot of delay by year and herd (Figure 16) shows minimal crossing delays (not taking into consideration those that deflected around the road) up to 2018 with higher crossing delays for the Lorillard and Wager Bay subpopulations in 2018, and the Lorillard subpopulation in 2019. Note collar subpopulation representation changes from 2011 through to 2015. Following 2015 most collars were deployed on Lorillard cows.

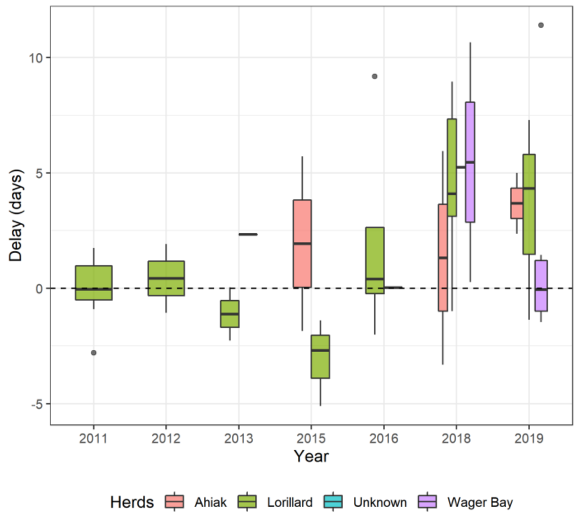

Figure 16. Estimates of delay in migration along the Meadowbank road system broken down by caribou subpopulation. Data based on collar locations from 2011 to 2018 used for the ZOI regression analysis.

One other question of interest is whether caribou that were deflectors (moved north along the road and did not cross as shown in Figure 10) had different estimates of delay compared to crossers (Figure 17). In general, crossers experienced higher delays than deflectors which is most evident when estimates are pooled across years (Figure 17).

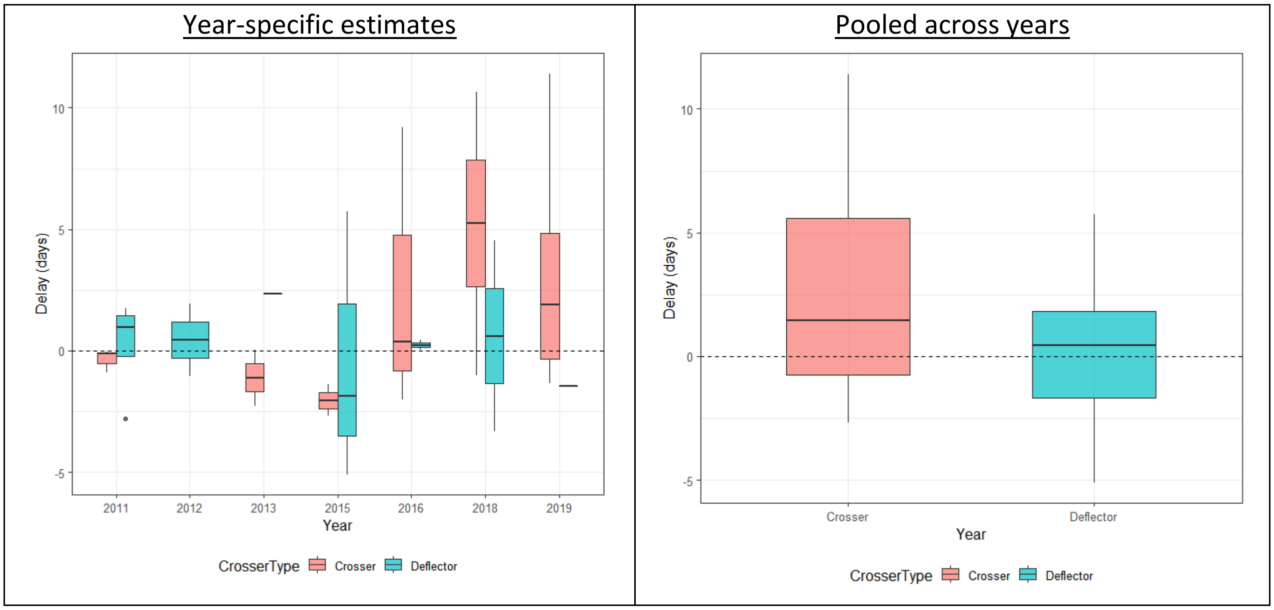

Figure 17. Estimates of delay in migration along the Meadowbank road system broken down by crossing behaviour (crosser or deflector as shown in Figure 10, for individual years (left) and pooled across years). Data based on collar locations from 2011 to 2018 used for the ZOI regression analysis.

It was also possible to estimate the distance travelled in the ZOI by the length of paths of caribou within the ZOI boundary. These lengths were then compared with the number of days a caribou was within the ZOI. Days in ZOI was a significant predictor of distance travelled ($\beta=5.9$, SE=0.82, CI=4.3-7.6, $t=7.3$, $p<0.001$). The distance travelled in the ZOI for caribou that had no delay was 37.1 km (min=19.0, max=78.0, std. dev.=16.3, n=17), whereas the distance travelled for delayed caribou was 66.1 km (min=19.9, max=134.6, std. dev.=30.4, n=29). Caribou were predicted to travel up to 100 km within the ZOI when they were in the ZOI for 12 days. Caribou that were not delayed spent up to 4 days in the ZOI whereas caribou that were delayed spent from 1 to 12 days (Figure 18).

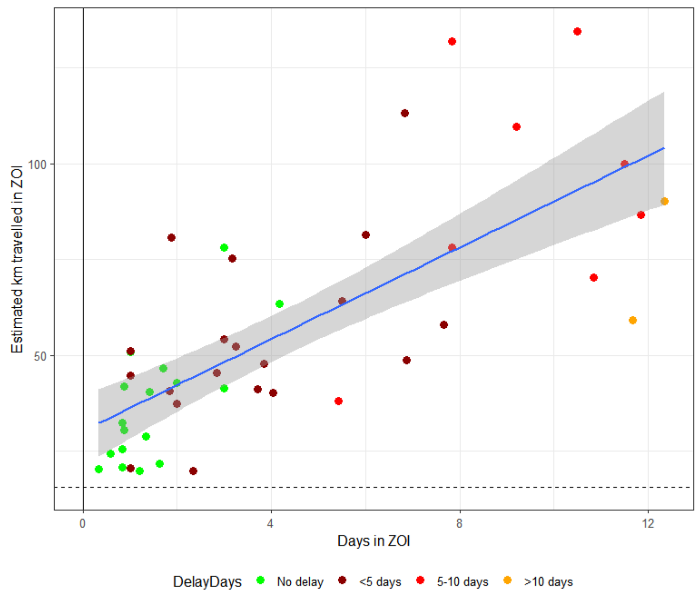

Figure 18. Estimated distance travelled in ZOI as a function of days within the ZOI. The colour of symbols corresponds to caribou that were not delayed (green) or caribou that were not delayed (red and orange as indicated in legend). The predicted line for a linear regression model is shown.

5.5 Effect of road closure on road crossing

As an initial step in the road closure analysis the sequence of road closures were evaluated relative to the crossing dates for 2018 and 2019 (where road closure data was available). Figure 19 reveals that the Whale Tail road was closed for a substantial portion of the spring migration season in 2018 and 2019. The majority (17 of 23) crossing events occurred when roads were closed. Roads were closed when collared caribou were within the ZOI for 46% of locations in 2018, and 73% of locations in 2019, for all locations within 20 km of the road used in this analysis. This ensured reasonable sample sizes for individual collared caribou in the analysis while being in the range of estimated ZOI's. Only locations with a fix interval of 4 hours were included in the analysis. Based on 901 locations, the mean distance moved between 4 hour fixes was 1.62 km (st.dev=1.9, min=0.0, max=13.5, n=23 caribou).

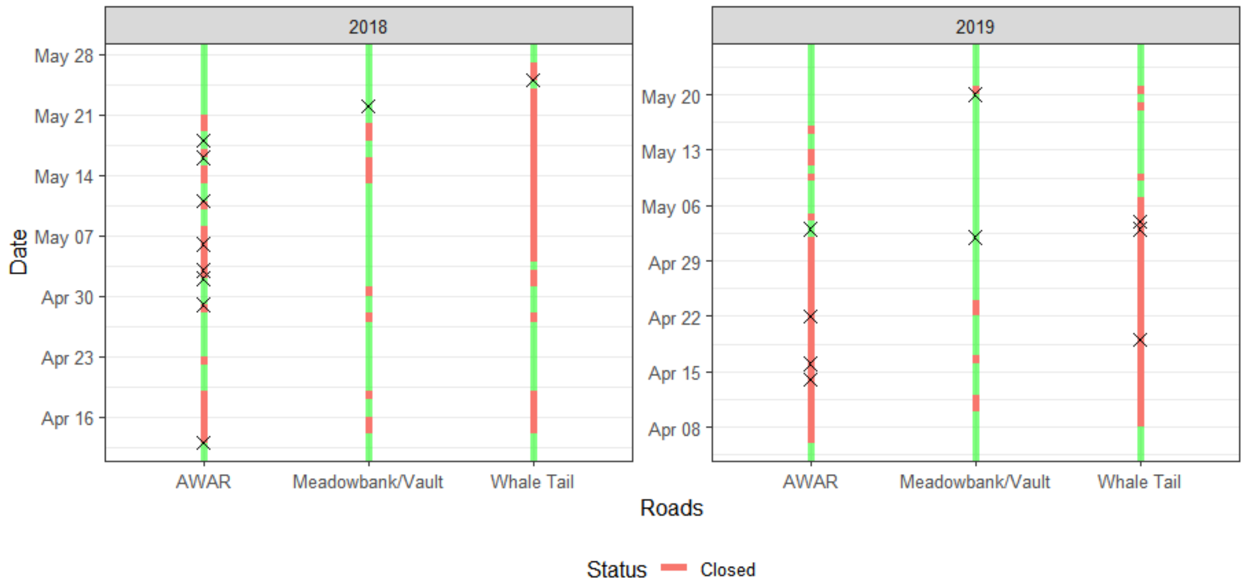

Figure 19. Status of the AWAR, Meadowbank/vault, and Whale Tail roads in 2018 and 2019. A green color indicates the road is open to traffic and red indicates the road was closed to all but essential traffic. The X markers indicate dates of crossing for collared caribou on each road.

We note that a road closure did not mean no traffic, though traffic was substantially reduced during road closure periods. During road closures traffic deemed essential would move down the road in slow moving convoys. Additionally, vehicles with caribou observers would patrol the roadways on a regular basis for the purposes of determining when a road would be closed, and again re-opened, based on observations of caribou in close proximity to the road. Unfortunately, information on convoy size, timing, section of road used, and observation vehicle timing and frequency, were not made available for this report. We also point out that the traffic levels on the whale Tail road extension are significantly higher than those for the AWAR due to the Whale Tails status as a haul road.

An assumption of the road closure analysis is that caribou were exposed to roads when they were open and closed and therefore had a potential choice to cross based on the level of traffic on the road. Inspection of frequencies of locations categorized by the nearest road (Figure 20) suggests this assumption is reasonable for the AWAR road with roughly equal frequencies of locations when the road was open and closed. However, for the Whale Tail, the majority of locations occurred when the road was closed. Of 23 collared caribou, only 5 encountered the Whale Tail road, 4 encountered both the Whale Tail and AWAR/Meadowbank/Vault roads, and 14 only encountered the AWAR road. Of the 4 caribou that encountered both the AWAR/Meadowbank/Vault roads, and Whale Tail roads, all but 1 had the majority of its locations on the AWAR road (mean proportion of locations near AWAR=0.91, min=0.36,max=1, n=19). However, 3 of the 4 caribou initially traversed the AWAR road before crossing on the Whale Tail haul road.

Few locations occurred near the Meadowbank/Vault and therefore it was pooled with the AWAR for the majority of analysis.

Figure 20. Frequencies of locations (right figure) and crossing events (left figure) relative to roads as delineated by road status.

A good example of a caribou encountering all the roads was BL670415 in 2018. In this instance BL670415 traversed the entire AWAR road before crossing the Whale Tail road during a closure on May 25th, 2018 (Figure 21). Individual paths of caribou are shown with model predictions later in this section.

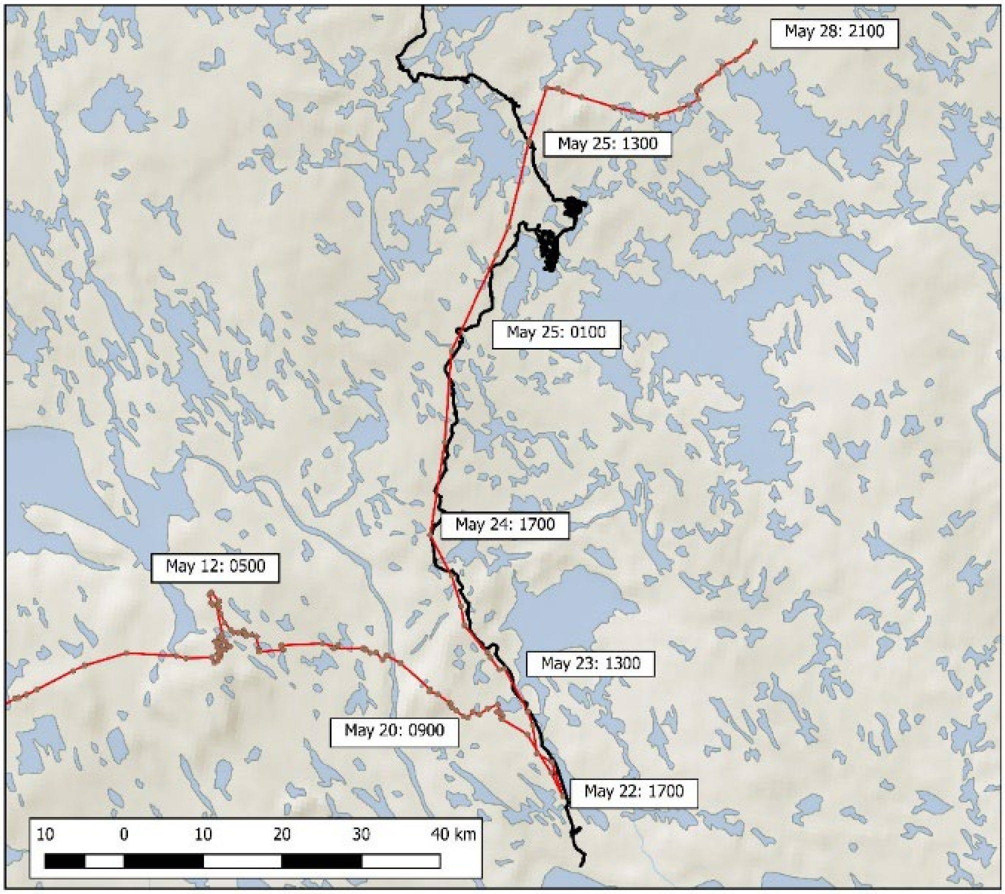

Figure 21. The path of BL0670415 in 2018. Note this caribou cow traversed the entire AWAR road and mine infrastructure before crossing the Whale Tail extension road during a road closure.

Given minimal encounters by collared caribou with the Whale Tail road when it was open, it was not possible to effectively parameterize the interaction of road and road closures as a function of the Whale Tail or AWAR roads. To confront this issue, the analysis was conducted with three data subsets: the full data set including caribou encounters along both the AWAR and Whale Tail roads, caribou that primarily encountered the AWAR, and caribou that only encountered the AWAR. The full data set analysis assumes that the primary factor affecting caribou crossing is closure and not road type. The Primarily AWAR analysis utilizes caribou that mainly encountered the AWAR/Meadowbank/Vault roads (91% of locations) but allows for caribou that did encounter the Whale Tail road (of which 3 of 4 crossed on the Whale Tail). The AWAR only analysis subsets to only caribou that encountered the AWAR and Meadowbank/Vault and excludes caribou that had any locations in the vicinity of the Whale Tail road.

The model terms included distance from road and whether a road was closed. Distance from road was controlled for the likelihood that caribou near a road had to move less to cross the road and were therefore more likely to cross. It was possible that caribou might respond at different distances to a closed or open road, so an interaction between distance from road and road closure was modelled. Preliminary model runs that included maximum temperature at Meadowbank (MaxTemp) and Lake Ice (Ice), which were supported predictors for movement, determined these terms were not significant predictors of crossing events.

Model results with the three data subsets suggested that road closure was a significant predictor of probability of crossing (Table 8). The effect of road distance on crossing was most pronounced when a road was closed versus when it was open as indicated by the magnitude of slope terms and parameter significance. Relatively similar results occurred across all data set formulations.

Table 8. Road closure analysis parameter estimates from a conditional logistic regression of road crossing.

Road Closure Parameters	Estimate	SE	Z	Pr(>|z|)
All roads included (n=23 caribou)				
Road closed	3.68	1.13	3.24	0.001
Road open X dist from road	-0.09	0.12	-0.77	0.439
Road closed X dist from road	-3.92	1.19	-3.30	0.001
Primarily AWAR road (n=18 caribou)				
Road closed	4.53	1.02	4.46	0.000
Road open X dist from road	-0.05	0.10	-0.48	0.634
Road closed X dist from road	-4.43	1.21	-3.64	0.000
AWAR-only (n=14 caribou)				
Road closed	4.30	1.17	3.66	0.000
Road open X dist from road	-0.04	0.11	-0.35	0.726
Road closed X dist from road	-4.63	1.35	-3.43	0.001

A plot of model predictions relative to distance from road further suggests that the relationship between distance from road and crossing probability mainly applies to when the road is closed (Figure 22). One way to conceptualize this is when the road is open, traffic might prevent crossing when a caribou is near the road and therefore road distance does not influence crossing. When the road is closed a caribou is more likely to cross the road when in the proximity of the road, so the relationship between distance from road and crossing probability is more defined. Probabilities of crossing increase at approximately 12 km from the road when it is closed.

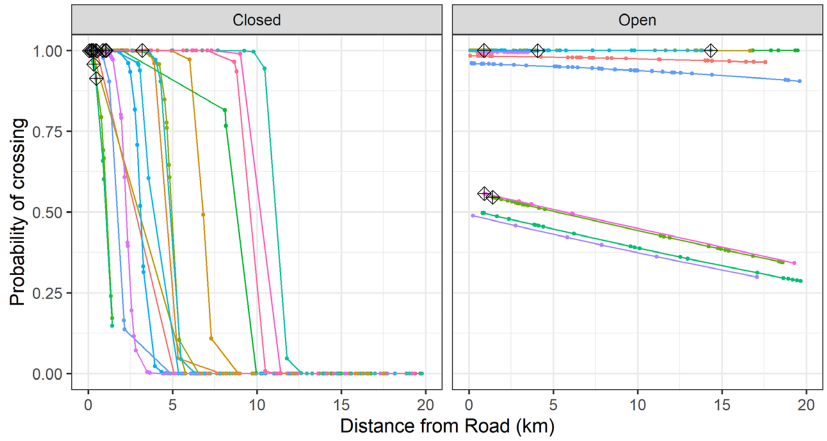

Figure 22. The estimated relationship between distance from road and crossing probability as a function of road status for the Primarily AWAR road data formulation (Table 8). Note that individual caribou trajectories may appear on both curves dependent on whether the road was open. The last location before crossing is given as a symbol.

The overall analysis and model results are best conceptualized through viewing the individual caribou paths (Figure 23) for the primarily AWAR analysis run (caribou that only used the Whale Tail not shown). In this figure caribou locations are colored by road status (green—road open to traffic, red—road closed). Above each graph the caribou id and estimated delay from the ZOI/regression analysis is given. We found that in the spring of 2018 and 2019, 6 of 18 caribou had delays of 1 or less days (as estimated the ZOI analysis), and of these, 5 crossed when the road was closed. Of the remaining 12, 4 crossed when the road was open, and 8 crossed when the road was closed. These results suggest that closure of roads reduces delays but does not completely eliminate delays. As discussed later, other covariates such as roadbed height and snow bank size might help explain delays when the road was closed to traffic. Additionally, it is unknown whether essential traffic allowed through during road closures may have had any effect on these observations.

A few paths are noteworthy such as BL0670415_2018 that traversed the entire AWAR road (that was open to traffic) before crossing at the Whale Tail (that was closed). In other cases, such as BL2018002_2018 the road was closed to traffic when the caribou was in its vicinity, but it did not cross. The road then re-opened and the caribou still did not cross instead traversing around the road across Baker Lake. Other caribou, such as BL0600415_2018 and BL0690416_2018 approached the road when it was open then stayed in the vicinity of the road for 4-5 days before crossing when it was closed.

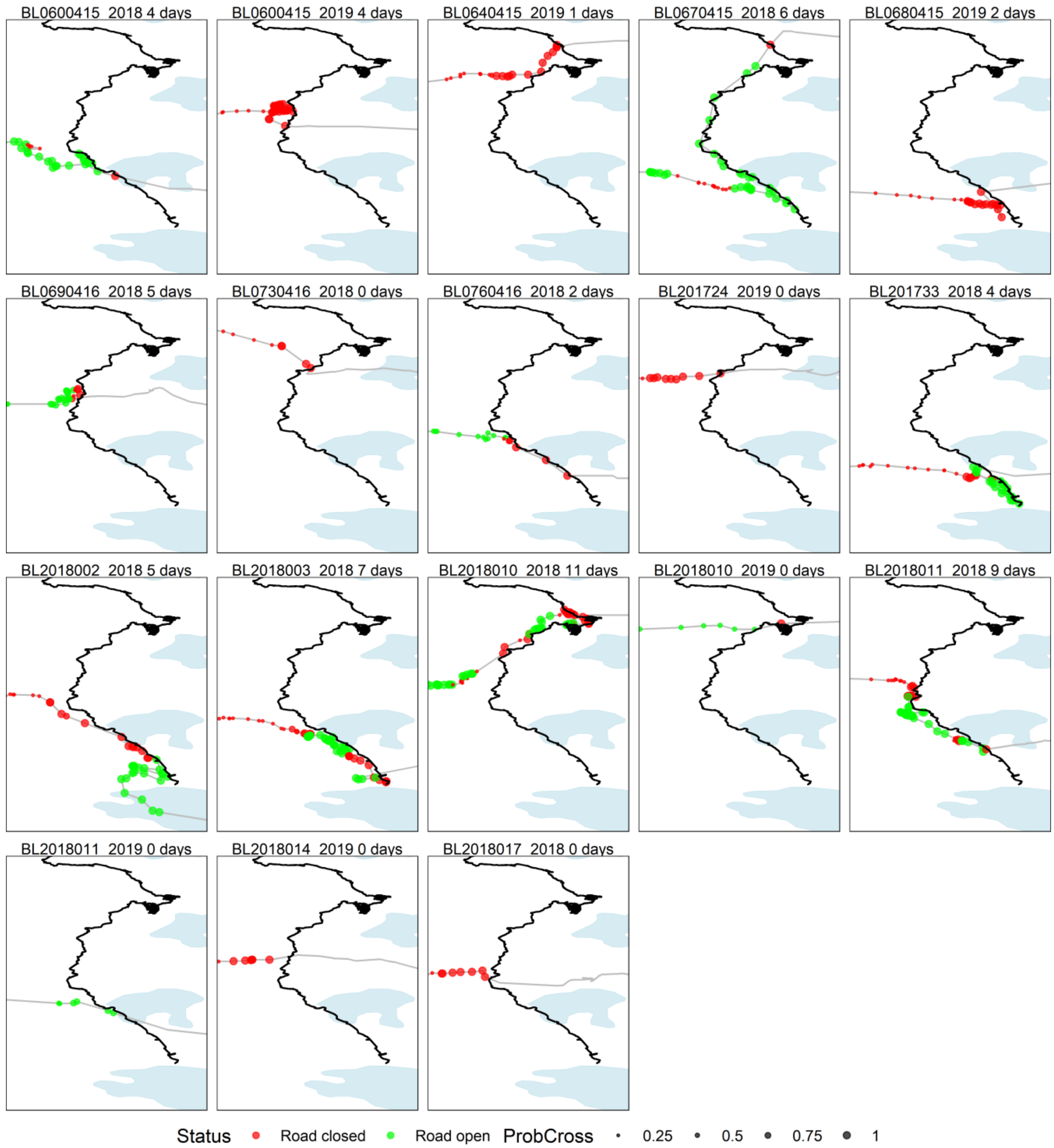

Figure 23. Paths of collared caribou from the road crossing analysis relative to the Meadowbank roads. The *id* of each caribou, and the estimated delay due to the road from the ZOI/regression analysis is given above each plot. The status of the road for each location is delineated by color and the estimated probability of the caribou crossing by symbol size. Caribou that only encountered the Whale Tail road are not shown in this figure. The figure is not scaled evenly to allow the fitting of all the caribou paths into a single plot.

5.6 Biased-Correlated Random Walk estimation of delay

Potential delays caused by changes in movement behaviours around road and mine site infrastructure, are important for migrating caribou under pressure to reach breeding areas, calving, and wintering grounds. Additionally, delays can increase energetic demands, disrupt feeding/ruminating cycles, and increase predation. An example of an observed trajectory for Lorillard caribou spring migration and its associated simulated trajectories, is presented in Figure 24. This example is based on the empirical distributions of step lengths and turning angles built from the observed data. While the spatial distribution of trajectories is wide at the start of the trajectory (in the wintering grounds to the west of the road), it narrows as the simulated caribou approach the final location.

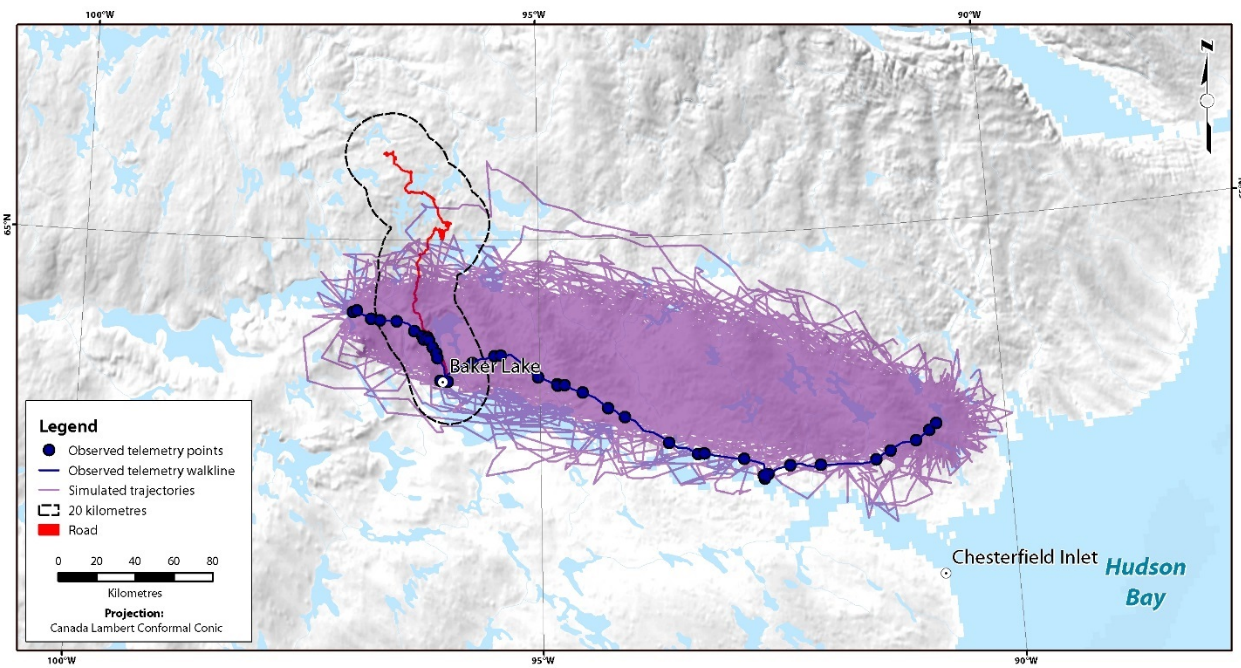

Figure 24. An example of a single caribou telemetry track (BL2018003_2018) in comparison to the 500 simulated trajectories calculated by the biased-correlated random walk (BCRW) model. The blue path is the observed telemetry points and walklines, while the purple illustrates all simulated trajectories. The delay in crossing time is calculated by the time it takes for the observed points (blue path) to enter the 20km buffer and cross the road. The same comparison is conducted for all simulated trajectories and the crossing times compared between observed and simulated paths.

The BCRW approach determined that 27 of the 42 caribou that crossed the road during the spring migration were ‘delayed crossers’, meaning that the observed crossing time was greater than the expected mean crossing time (Table 9 and Figure 25). For example, BL2018003_2018 was designated as a delayed crosser, spending 12 days within 20 kilometres of the road before crossing, in comparison to an expected time of 3 days. The observed mean number of crossing days for the caribou with delayed crossing times was 7 days (std. dev= 3, min=2, max=14 days), compared to a mean expected crossing time of 3 days. This means that on average these caribou had crossing times 4 days slower than would be expected if the road had no effect.

The group of caribou whose crossing times were not delayed had a mean crossing time of 2 days (std. dev= 1, min=1, max=4), which was similar to the expected value of 3 days. For all caribou in Table 4, the mean of the difference between observed and expected mean was 3 days (std. dev. =4, min=-2, max=12). A full list of the BCRW results is provided in Appendix 7.5.

Table 9. Summary of biased correlated random walk (BCRW) migration delays by year.

Year	Total collars	Delayed crossers	Average crossing delay (days)
2011	7	3	2
2012	2	2	1
2013	3	1	1
2015	5	3	3
2016	5	2	7
2018	13	10	6
2019	11	6	6

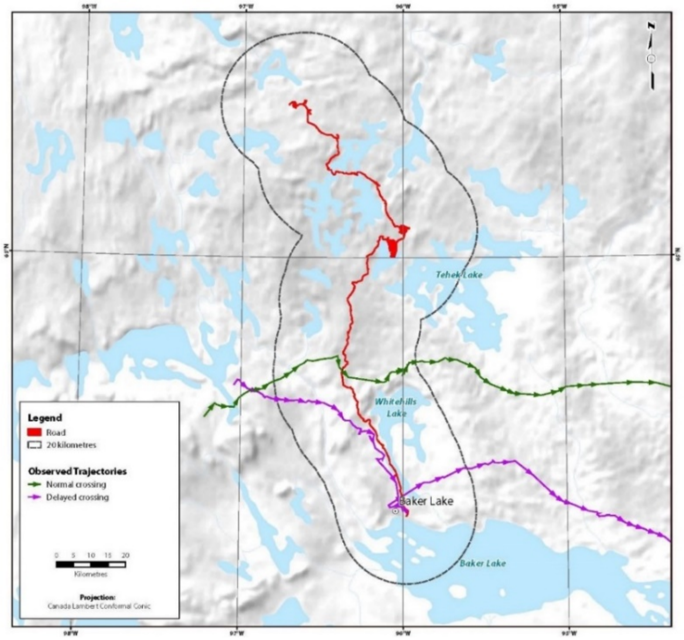

Figure 25. A comparison between two observed trajectories for the spring migration period, one classified as a normal road crosser (BL2018017_2018), and one as a delayed road crosser (BL2018003_2018). The normal crosser has relatively consistent spacing between telemetry points and an uninterrupted migration path. This particular animal does not show significant change in movement speed as it nears the road location. Conversely, the slow crosser shows more disjointed path characteristics surrounding the road, with many short and convoluted/meandering segments. These attributes show an overall slowing and interrupted path trajectory.

5.7 Comparison of delay from BCRW and ZOI

Estimates of delay using ZOI and BCRW methods were significantly correlated (Pearson's r =0.85, CI=0.75-0.92, t=10.3, p<0.0001). The highest level of agreement occurred when delay days were higher than 2 days (Figure 26).

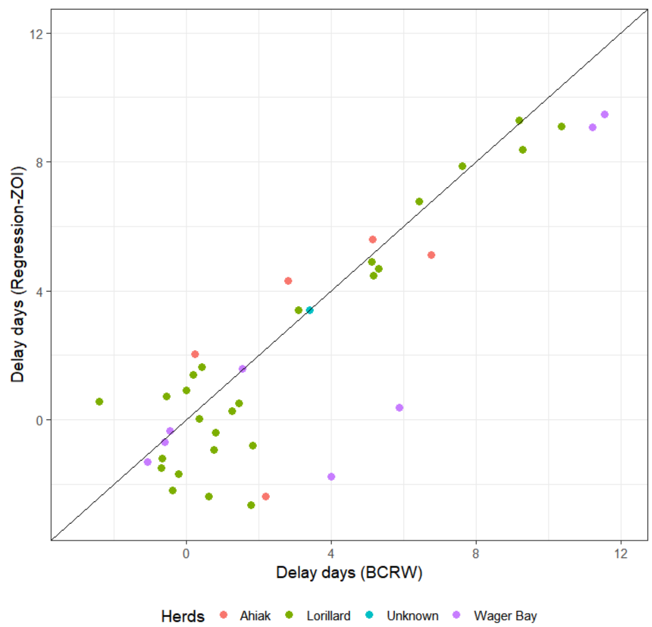

Figure 26. Comparison of estimates of delay from 2011-2019 using Regression-ZOI, and BCRW methods. Herds are differentiated using the plot symbology. The vertical line represents total agreement between estimates from each method.

Both methods also displayed similar temporal trends in delays with minimal delays up until 2018 when both methods produced similar estimates of delay (Figure 27).

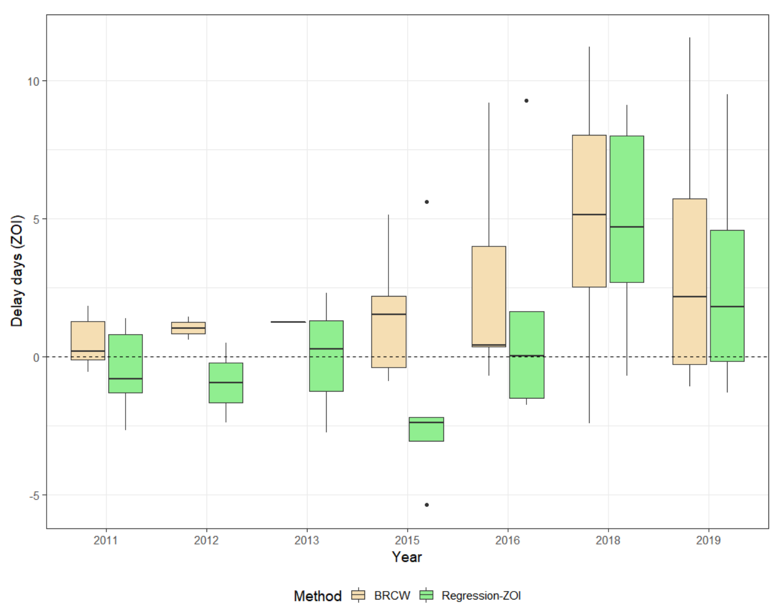

Figure 27. Comparison of estimates of delay from 2011-2019 using Regression-ZOI and BCRW methods.

6.0 DISCUSSION

6.1 General comments

The results of this analysis suggest that the effects of Meadowbank roads during spring migration vary on a year to year basis, presumably due to activity on the road, as well as proximity of caribou migration paths to road networks. The most common movement relative to roads is parallel movement which creates potential delays in migration, and increases overall distance travelled and as a result, energy expended. A challenge to this analysis is relatively low yearly sample sizes of caribou with less representation of the Wager Bay herd until the last year of the analysis. Despite these limitations, significant zones of influence, as well as delays, were estimated during the latter years (primarily 2018 and 2019) in which sample sizes were large enough to support an estimate. We summarize our results graphically by individual caribou with individual trajectories (Figures 14 and 15) as well as paths (Figure 23), shown to allow clear interpretation of analysis results given sample size limitation.

The estimated zones of influence of 16 to 17 km range appears to be beyond the likely sensory distance that a road can be detected. That being said, concentrated predation, dust plumes and olfactory stimulants could impact caribou well beyond visual and audible range. In addition, one other factor that might cause larger zones of influence is non-independence of individuals. For example, a larger group of caribou may detect the road creating delays of other caribou that are connected to, but lagged behind the larger group (Fagan et al. 2013, Calabrese et al. 2018, Foss-Grant et al. 2018, Martinez-Garcia et al. 2019). Therefore, actual response to the road may occur at scales beyond an individual caribou's perception of the road. This effect is biological and not a statistical artifact given that the lagging caribou are indirectly delayed by the road.

The mechanisms that cause zone of influence can be dichotomized into direct and indirect effects. Direct effects would include immediate stressors around the road such as high traffic volume, aggregate size used in road construction, dust, increased snow thickness (snow fence effect), noise, odour, road related predation, and other factors that could cause caribou to reduce movements around the road via visual, audible, olfactory, and physical stimuli. This is the type of zone of influence assumed in most caribou studies (Nellemann and Cameron 1996, Vistnes and Nelleman 2008, Boulanger et al. 2012, Flydal et al. 2019). Indirect effects would be factors that are associated with the road such as hunter access, use of the road as a travel corridor to allow easier access of predators to caribou, and other disturbance factors that would not exist if the road were not present. We note that the zone of influence estimates in this study will include both direct and indirect effects. The best way to tease apart direct and indirect effects would be the use of covariates such as traffic volume. Some of the most common co-variates can be broken down into haul truck traffic, hunter traffic including tracks of areas traveled off the road, hunter and predator kill locations, predator locations and movements, assessments of snow thickness and hardness along the road, and other physical and spatial data measured through time where appropriate. These types of covariates were not available for the analysis in this report.

Zones of influence were not detected for 2011-2016, however, it is likely the road did influence movements during this time as indicated by 55% of collared caribou being deflected north around the road rather than crossing the road directly (Figure 10). The full Whale Tail road was not present prior to 2018 and therefore caribou could pass north of the Meadowbank mine footprint and Vault Road. After 2018, the Whale Tail road blocked this potential path which reduced the proportion of deflectors to 13% in 2018 and 2019 with caribou 8.3 times (CI=2.1-43.4) more likely to cross rather than deflect around the Whale Tail, Vault, or AWAR road. The general effect of deflection is further illustrated when ZOI's of crossers and deflectors are estimated. In this case ZOI's were non-significant for deflectors with significant ZOI's for crossers (pooled across all years: 16.7 km (CI=6.2-27.3). Furthermore, deflectors showed reduced delays compared to crossers (Figure 17). Therefore, it is likely that deflective behaviour prior to 2018 reduced the amount of time that caribou interacted with roads therefore reducing the power to detect ZOI's for this time period. Higher sample sizes of collared caribou would increase the relative power to detect ZOI for deflectors given the lesser magnitude of measurable road effects.

The base regression model identified both habitat and environmental factors that influenced movement rates relative to mine roads. First, caribou movement was higher as temperature increased, however this effect may have been partially due to seasonality given that temperature increased over the course of spring migration. Other studies of migratory behaviour (Gurarie et al. 2019) did not find linkages in movement rates between weather during migration, but did suggest that migration movement rate was related to weather in the previous fall and summer which may influence caribou condition. We modelled yearly variation in movement using a year term allowing for unique mean movement rates for years of interest. Of habitat classes considered, the use of ELC water/ice class was most supported. This class mainly corresponded to smaller waterbodies rather than larger lakes which were usually not traversed. We speculate that smaller frozen water bodies with snow may provide smoother travel conditions than areas with shrubs or rockier areas.

Both the ZOI and biased correlated random walk analysis suggested that the road and/or its effects delayed spring migration through the modification of caribou behaviour and movement patterns. Reasonable agreement in delay estimates from both methods is reassuring given the different assumptions of the respective analyses. Both approaches consider variance in the path of caribou during its migration, however, the ZOI approach assumes that the main variance that will cause the delay occurs within the estimated ZOI. Using both approaches provides a cross-validation of the assumption of the ZOI. The ZOI approach can be further constrained to consider the effect of weather covariates and other factors that might influence delay. The graphical representation of predictions (Figures 14 and 15) also allows intuitive representation of caribou paths relative to the road, and potential delays relative to road type and road closure.

The road closure analysis suggest that closure of roads can be used to increase the probability of caribou crossing and therefore reduce delays. We suggest that the approaches developed in this analysis can be used to assess the adequacy of road closure. For example, if road closures are effective then the relationship between distance from road and road closure will become more defined, and estimated delays should decrease. The movement trajectories (Figures 14 and 15) also allow an assessment of the amount of time a caribou was within crossing distance of the road while it was open versus closed. More exact road closure data would help sharpen predictions of the model. To more precisely determine the effectiveness of road closures, quantitative and reliable essential traffic data will be required, and should be incorporated into any future analysis.

We note that it was not an objective of this analysis to infer demographic impacts of delays in migration due to the road. This type of analysis, which would require the use of demographic modelling, was beyond the scope of the current analysis. We do believe, however, that the results of this analysis set the foundation for further study into demographic consequences to the observed behavioural modifications in this specific road analysis. The potential demographic consequences of roads are delays in migration, potential energetic costs, the fragmentation of migration routes (Panzacchi et al. 2011, Panzacchi et al. 2012), and increased mortality in the proximity of roads due to predator and harvester access. The zone of influence measurements in this paper only consider delays, and are possibly influenced by the above effects variables disrupting movements relative to roads. Further covariates, such as harvester road traffic, and predator sighting indices and use and predation studies, would be needed to better understand these effects.

One assumption of this analyses is that caribou are exhibiting migratory behaviour which obligates them to cross the road. Using the data from the Lorillard herd helped meet this assumption given the East-West and West-East migration pattern relative to their calving and wintering grounds in most years. Other herds such as the Ahiak and Wager Bay, have calving grounds at higher latitudes than the mine, and in the case of the Ahiak herd, wintering grounds further west. As a result, the migration paths of these herds may not always traverse through the mine area as they express a different trajectory than the Lorillard (Campbell et al. 2014). Directional migration behaviour for the present analysis was certainly evident for the spring migration as shown in date plot figures (Figures 6 and 7).

6.2 Zone of influence estimation

Zone of influence provides a standardized metric to consider the spatial impact of the road across years and seasons. Unlike other metrics, it provides *a statistical estimate of both spatial extent and magnitude of effect of roads or other stressors that can be compared temporally and between studies* (Boulanger et al 2011). Zone of influence can be used to better develop and assess mitigation measures such as road closure by estimating zones of influence when roads are closed versus not closed.

Our approach to this analysis has been to first develop graphical methods to efficiently show patterns in the data followed by more substantive statistical analyses. The date trajectory plots (Figures 3-5, and 14-15) provide a way to show relative movement of caribou in the vicinity of the mine roads. Effects of the road are indicated by vertical trajectories near the road compared to distances further from the road, and/or movements away from the road, counter to migratory direction. This novel graphical approach is then built upon by the quantitative zone of influence analyses. Predictions of zone of influence are plotted with the raw point data to further allow readers to evaluate the relative fit and support of ZOI models.

An interesting finding of the ZOI analysis was the identification separate ZOIs prior to and after crossing the road. A ZOI prior to crossing the road is easily explained by caribou displaying potential blocking or aversion responses resulting from the road, and therefore restricting movement. The zone in this context is defined as the area where caribou movements (as indicated by ΔD_{mine}) were influenced by the road. Movement responses included lower movements toward the road, increased movements rates parallel to the road (Figure 13), and movements away from the road. The ZOI after crossing, which was smaller, was potentially due to gregarious behaviour, as well as increased movement rates after crossing the road, to compensate for delays in migration, especially during the spring migration period. Once caribou moved past the ZOI, ΔD_{mine} values were equal to or higher than those prior to crossing. The general finding of increasing movement rates of caribou if their migration is delayed by having to cross a road, has been found in other studies (Panzacchi et al. 2011, Wilson et al. 2016).

The regression analyses account for non-independence of repeated locations of caribou by using the generalized estimating equation approach to estimate parameter significance and confidence limits. However, analyses do assume independence between individuals which may be partially violated by gregarious behaviour, especially during spring migration. Inspection of movement trajectories (Figure 11) suggests that caribou migration occurred across a range of dates as indicated by the spread of trajectories. Further randomization methods could be used to better explore the effect of non-independence of collared caribou on estimates. The most likely result of non-independence would be lower precision of estimates rather than bias in point estimates of zone of influence.

Caribou that were live captured away from roads are included in the analysis while those captured within 20 km of the roads were not. Model selection results did not detect different zones of influence based on capture location in 2018 (Table 3). The effect of live capture on caribou response to roads is explored in detail in Appendix 7.5. The findings suggest minimal sensitivity of analyses to the removal of when live capture occurred in 2018. Assessment of movement trajectories of caribou after capture does not suggest larger scale movements after capture. Removal of the 6 caribou captured in 2018 further from the road is challenged by reduction of overall sample size of collared caribou in the data set from 13 to 7 (caribou captured prior to 2018). Estimates of ZOI and delay still occur in 2018 with removal of caribou captured previously, however, estimate precision is reduced. Estimates of ZOI are unchanged for 2019.

Given the variability of caribou movements relative to the mine footprint and roads, various metrics need to be considered to measure caribou response to the mine roads. The results of the analysis suggest that change in daily distance from the mine ΔD_{mine} during spring migration, is a useful metric especially when caribou interact directly with the mine road and are directly east or west of the mine roads. This metric directly measures the interaction of the caribou with the mine road. If caribou are moving directly toward the mine road then values will be higher for a given path length then if the caribou are moving parallel, away, or milling near the road. Movement rates often increase in the proximity of roads (Figure 13) and therefore movement rate does not readily equate with delay in migration, but can provide an additional metric to understand response to roads and possible demographic effects yet to be explored. Increased movement in proximity to roads, has been documented in other studies of caribou and road interactions (Panzacchi et al. 2011, Wilson et al. 2016). In contrast, tortuosity, used in previous analysis, considers relative complexity of path and therefore may show similar values if a caribou is moving toward or away from the mine road. Tortuosity is potentially a better metric when caribou are at further distances from the mine road given that it will be more sensitive to small scale variation in path complexity. Increases in frequency of daily collar reporting should be considered to help improve the results of these types of analysis into the future.

6.3 Data gaps in analysis

A data gap in this analysis is relative traffic volume, given that the impact of a road with high traffic volumes is likely to be very different than a road with minimal traffic. For example, roads were closed intermittently during spring migration which may have assisted in caribou crossing though did not resolve the problem. During these closures traffic termed “essential” was allowed on the road though its volume and frequency is not known. In addition, traffic volume on the Whale Tail is likely to be different than the all- weather access road as the whale tail road is a haul road. Further, the all-weather access road may also be used for hunting which would create a different response than constant vehicle traffic. Finally, the use of the road corridor by predators to access caribou that are delayed by either direct and/or indirect road related effects, can further complicate disturbance mechanisms and demographic impacts. Ideally, both traffic volume and road use information could be used to better understand the mechanisms causing the negative behavioural effects observed on caribou, and assess the utility of the timing and duration of road closures to crossing behaviour in an attempt to try and mitigate these negative effects. In the absence of traffic volume data, it would have to be assumed that traffic volume was constant throughout the entire time in which caribou were in the vicinity of the road (to allow assessment of road closure on caribou crossing).

Our analysis of the Whale Tail haul road occurred before it was in full operation and therefore it is likely that the overall effect of this road on delaying migration was underestimated. When in full operation, traffic on the Whale Tail Haul road will be at least one large haul truck every 6 minutes (Golder 2018). We also note that traffic volume on both the Whale Tail and AWAR road vary seasonally and therefore our analysis did not capture the full range of traffic on these roads. During the spring, traffic on the AWAR is fairly minor since it is not sea-lift resupply season, however, without detailed traffic volume information a firm assessment is not possible.

The other limitation to the analysis was lower sample sizes of caribou over some years/seasons (most particularly the period between 2011 and 2015) which reduced power and resolution to estimate ZOI and assess distribution of caribou relative to the road. In addition, fix interval was 24 hours in 2011 and 2012 and therefore the resolution of the collar data was limited. A larger sample size of collars would improve resolution of ZOI estimates including more detail on seasonal and yearly variation in caribou response to the Meadowbank road and other roads and linear developments on caribou range. The power to detect a ZOI will be influenced by collar sample size and the magnitude of the effect (how much does ΔD_{mine} change as caribou come closer to the mine in relation to areas further from the mine), as well as the statistical method employed to estimate ZOI. The analyses in this report used an analysis of covariance approach to estimate ZOI where primary factors causing variation in ΔD_{mine} were included in the model, and ZOI terms were added individually to obtain the most parsimonious model to estimate ZOI. Simulations could be used to further assess power to detect zones of influence; however, this type of analysis is beyond the scope of the current report.

6.4 Additional Work

The analyses in this report detail the development of new metrics (ΔD_{mine}), new methods to display migration data, as well as season and road-side specific zones of influence. The analysis has substantiated significant effects, either direct or indirect, of the road on caribou behaviour and associated movement patterns. Further analysis could include:

- More detailed information on road infrastructure that could be used in the road crossing analysis. Bank height and other factors will likely affect road crossing and could be used in the analysis.
- More detailed road closure data. The fix interval is 4 hours and therefore road status could be supplied at this interval rather than a daily interval.
- Traffic volume data could be used to better assess differences between roads and road closure strategies
- As noted earlier, further analysis of the impact of the Whale Tail road on caribou movements when in full operation (with higher traffic volumes) is warranted.

We note that this report details the analysis of spring migration data and does not consider the impacts of the road on caribou movements in the late summer and fall. These impacts include the effect of the road in limiting migratory behaviour as observed in the fall of 2016 as well as aggregation of caribou near the road with looping behaviour in the vicinity of the road in 2018. Analysis of the late summer and fall season is ongoing with the use of step-selection functions and other approaches to describe caribou movements relative to the road.

7.0 APPENDICES

7.1 Ecological Land Classification habitat classes

Table 12 and Figure 28 below shows the pooling of ELC groups (Campbell et al. 2012) used in regression analyses as discussed in Kite et al (2017). Note collar position data accurate to a mean of 3 meters.

Table 10. Ecological Land Classification (ELC) groups used in the analysis. The grouping of the two covariates used in the analysis are given by numbered groupings.

ELC Group	Group	ELC_ModeF	ELC_ModeP
Water	Abiotic	1	1
Wet Graminoide	Biotic	2	2
Graminoide Tundra	Biotic	2	2
Graminoide/Heath Tundra	Biotic	2	2
Graminoide/Shrub Tundra	Biotic	3	3
Shrub Thicket	Biotic	3	3
Shrub Tundra	Biotic	3	3
Shrub/Heath Tundra	Biotic	4	3
Forbe (Dryas) Tundra	Biotic	4	3
Heath Tundra	Biotic	4	3
Heath Upland	Biotic	4	3
Heath Upland/Rock Complex	Biotic	5	4
Lichen Tundra	Biotic	5	4
Lichen/Rock Complex	Biotic	5	4
Sand	Abiotic	6	4
Boulder/Gravel	Abiotic	6	4
Rock	Abiotic	6	4

Figure 28 provides a plot of ELC classes for caribou locations used in the analysis.

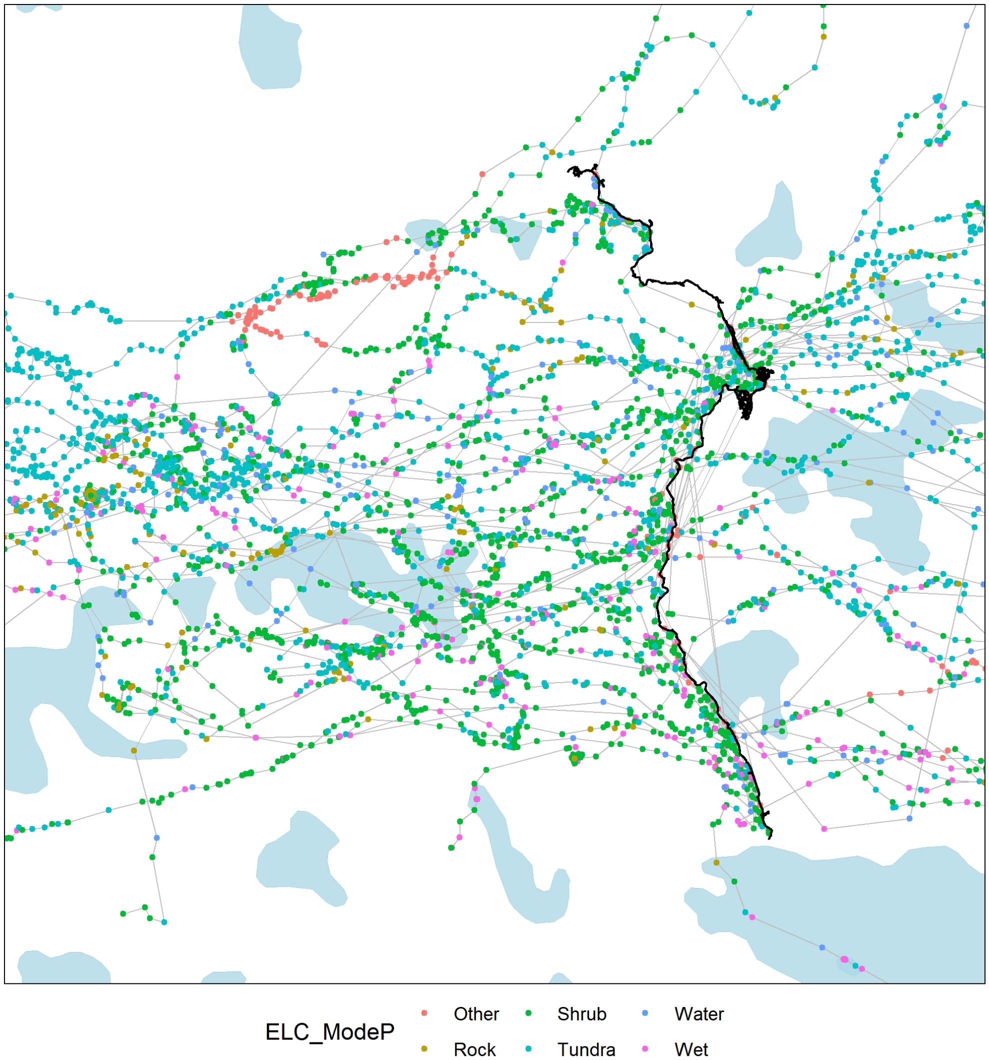

Figure 28. ELC classes for caribou locations used in the analysis.

7.2 Weather covariates used in the analysis

We summarized weather data from the Baker Lake Airport and Meadowbank mine to allow testing of correlations between weather factors and movement rates relative to the meadowbank mine. We chose weather covariates based on availability, as well as, previous studies (Gurarie et al. 2019) of factors affecting caribou migration. Temperature and wind speed data was avaiable from the Meadowbank mine airport, and temperature, precipitation, snowfall, and other metrics were available from the Baker Lake airport (Table 11). It is likely that the same broader scale weather conditions occur for the Meadowbank and Baker Lake areas. This was tested using temperature data collected in both locations.

Table 11. Weather covariates used for movement analysis.

Covariate	Acronym	Source
Average temperature	Temp_Avg_BL	Baker Lake
	Temp_Avg_MBK	Meadowbank
Max temperature	Temp_Max_MBK	Meadowbank
Average Windspeed	WindSpeed_Avg_MBK	Meadowbank
Extreme wind gust speed	Extreme_Gust_Speed	Baker Lake
Total daily precipitation	Precip_total	Baker Lake
Daily snow	Snowfall_total	Baker Lake
Freezing Rain	Freezing_Rain	Baker Lake
Snow on Ground	Snow_on_ground	Baker Lake

An initial comparison of Meadowbank and Baker Lake temperatures demonstrates that they are reasonably correlated (Figure 29).

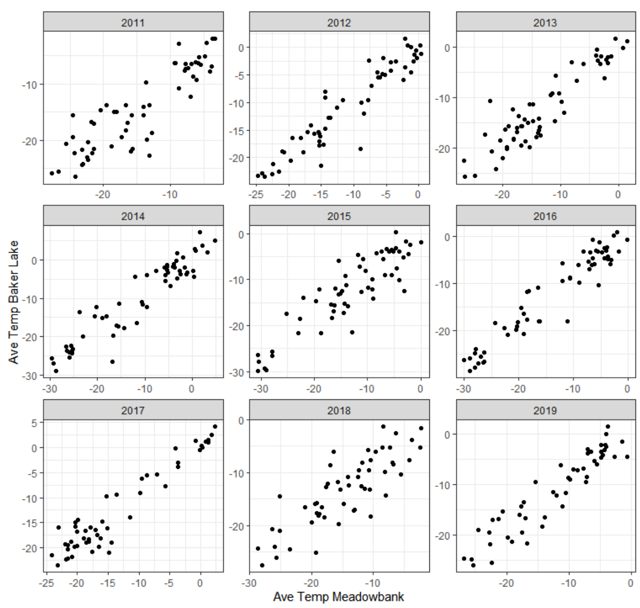

Figure 29. Average temperature in Meadowbank versus Baker Lake.

A plot of trends in the main weather covariates suggest directional trends in temperature (positive) and snow depth (downward) with less evident trends in wind speed and precipitation (Figure 30). Gust speed was used to indicate wind due to missing data for 2012 for average wind speed from Meadowbank mine.

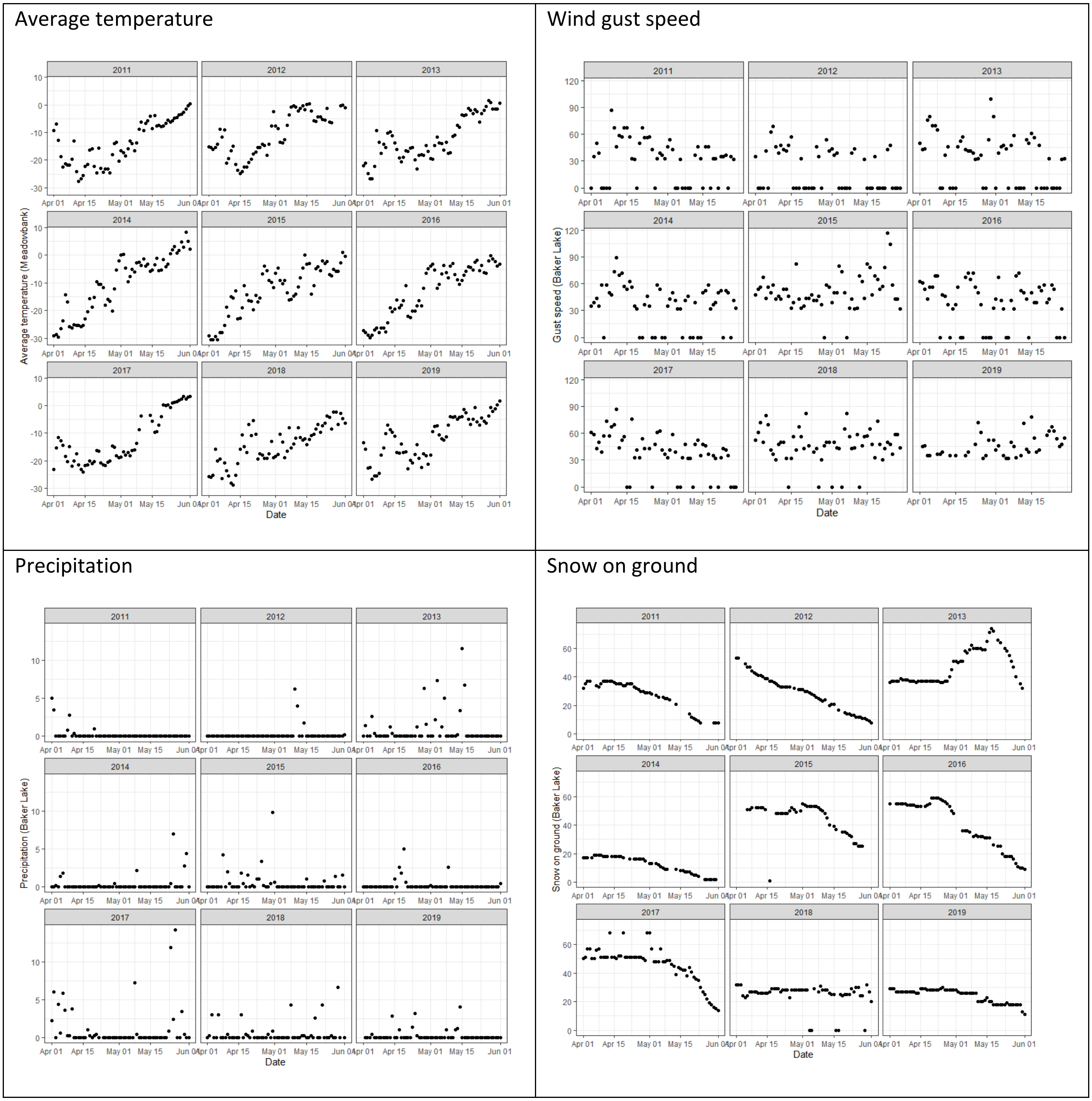

Figure 30. Trends in main weather covariates considered for the analysis.

Figure 31 summarizes inter-annual variation in maximum daily temperatures during spring migration.

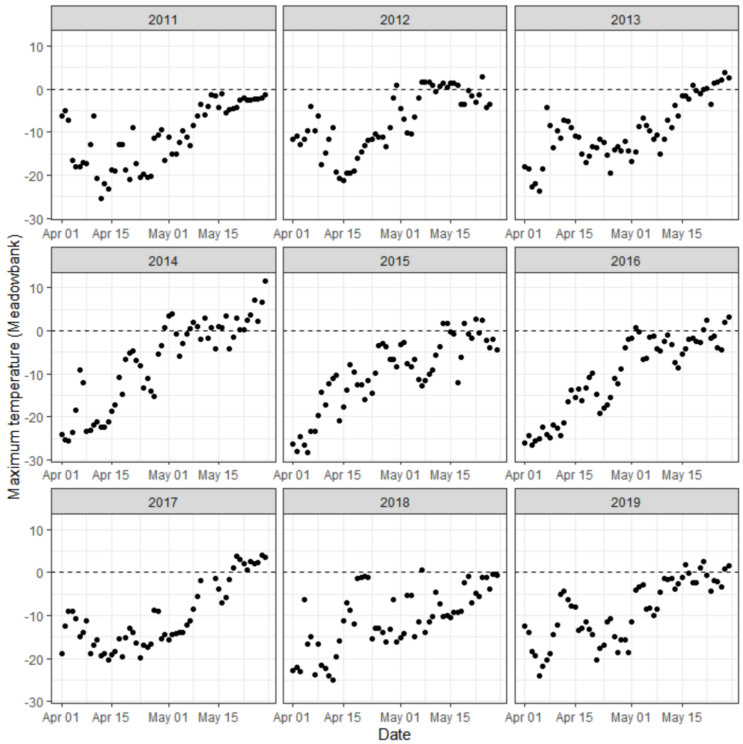

Figure 31. Yearly plot of maximum temperature during spring migration from the Meadowbank mine.

A correlation plot reveals that many of the covariate's values were correlated (Figure 32). In addition, to weather covariates, we added julian day to test for directional trends, as well as daily caribou movement rates and mine offset rates. These were a test for general correspondence rather than the more detailed model based approach in the main report. In addition, distance from mine was added with distances to the west of mine being negative and to the east being positive. This provided a test for an overall directional trend that was not dependent on whether caribou crossed the roads.

A few points are noteworthy in the correlation plot. First, many weather covariates showed some correlation with julian day, suggesting directional trends in some years. Second, movement rate and mine offset are minimally correlated with most weather covariates, suggesting there are no strong relationships between weather and movement. Finally, some weather covariates such as snow on ground, average temperature (in 2019), maximum temperature, and julian day, show some correlation further illustrating temporal trends in weather.

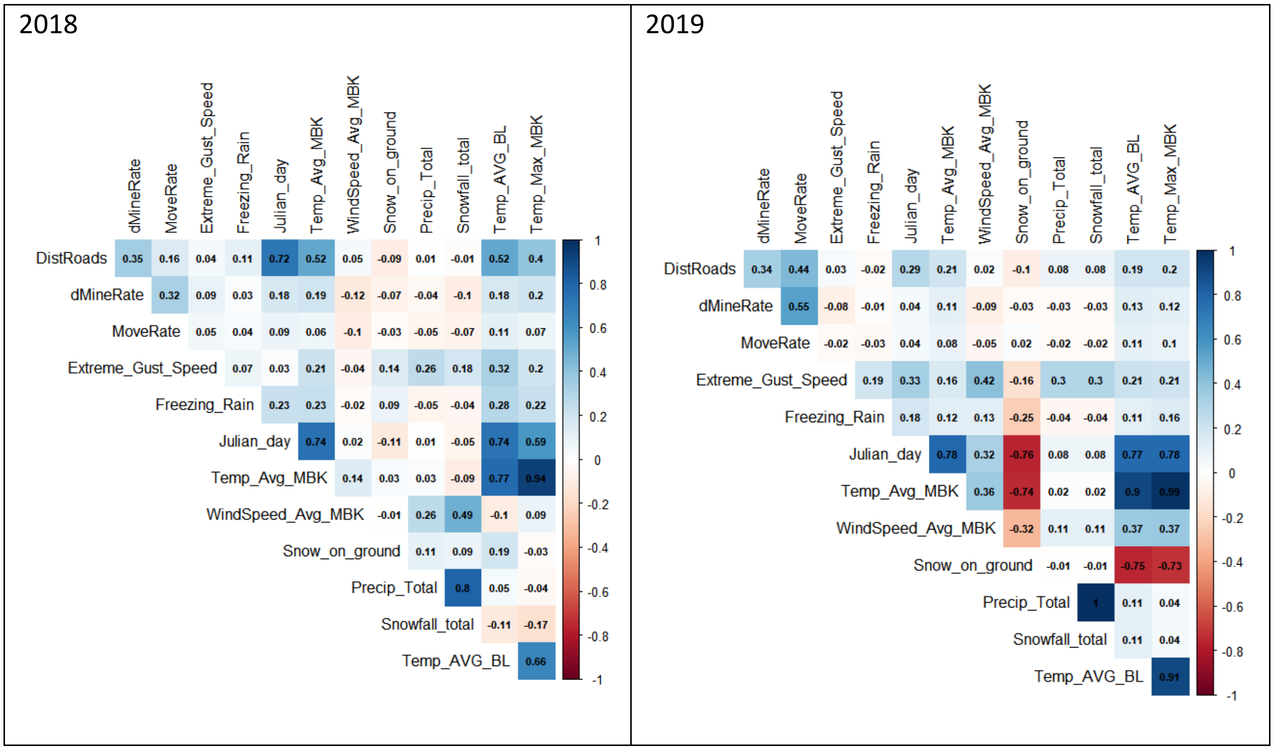

Figure 32. Correlation plot of weather covariates as well as movement rate, distance to mine roads, and mine offset rate. Correlations.

Most noteworthy was the recent study (Gurarie et al. 2019) which analyzed the effect of weather on various attributes including arrival of caribou at calving grounds. No trends were found between current weather and arrival of caribou on calving grounds. Instead, weather conditions in the summer prior to migration and pre-migration period which was presumably a latent effect that influenced caribou condition and subsequent movement rate during migration (Gurarie et al. 2019).

7.3 Details about data screening

The principal objective of analyses was to assess caribou movement relative to the Meadowbank road during spring migration. Given this objective many of the yearly paths of caribou were not applicable to the analysis since they did not come into contact with the road during that period. For example, one caribou came within 10 km north of the road in 2014, however, its overall trajectory was north of the road and therefore it was not included in the analysis. In addition, caribou that were captured in the proximity of the road (<20 km) were not included since it was likely that immediate capture effects would be confounded with road effects. A more detailed analysis of capture effects is presented in Appendix 7.6. Figure 33 shows paths of caribou coded by whether they were included in the analysis.

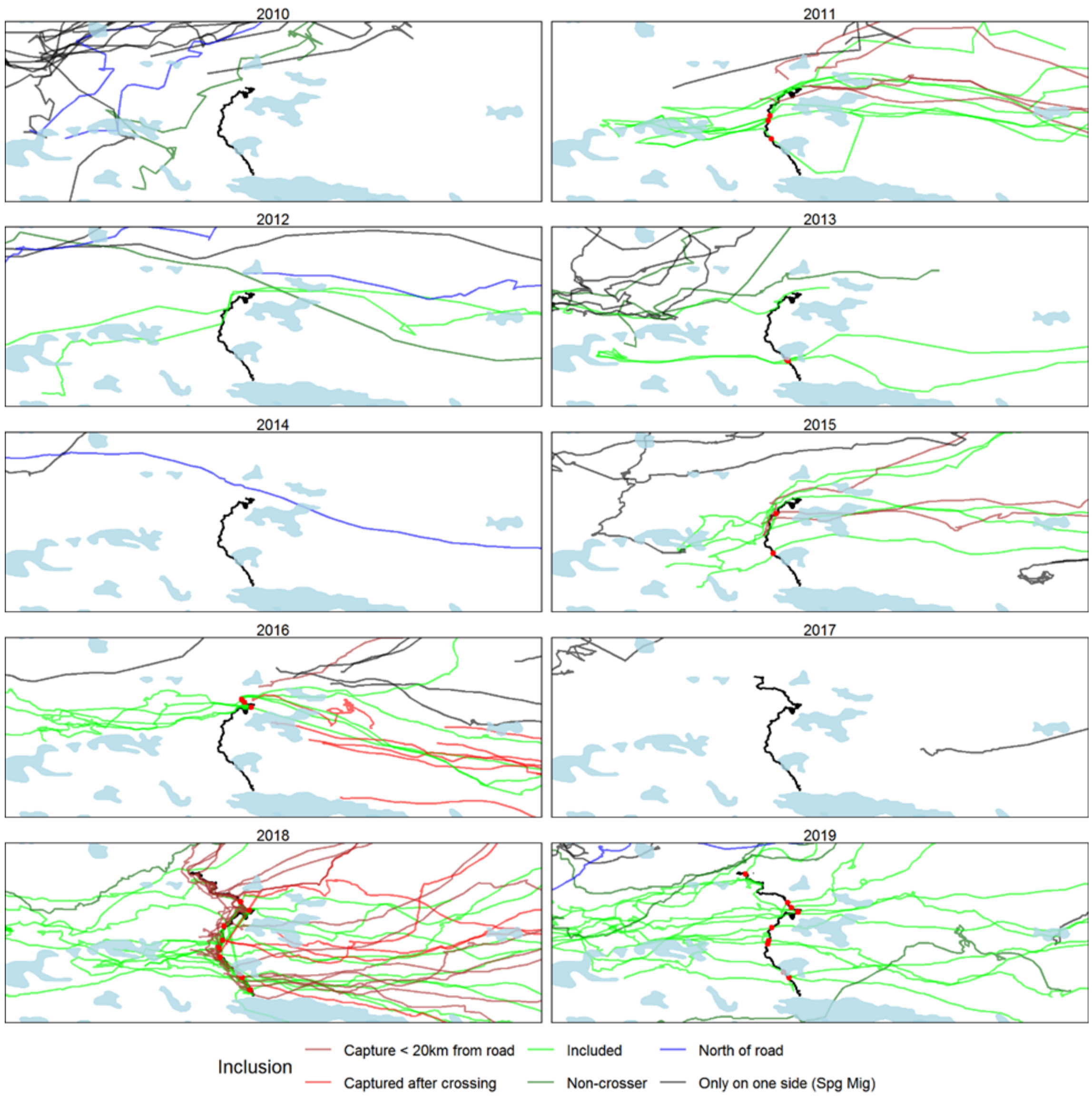

Figure 33. Spring migration paths of caribou as a function of whether they were included in analyses. Red points indicate crossing locations of caribou.

Sample sizes of each category dichotomized by herd are given in Table 12.

Table 12. Sample sizes of caribou excluded from analysis by herd. Sample sizes of caribou included is given in Table 2 of the main report.

Year	Herd				
	Ahiak	Lorillard	Unknown	Wager Bay	Total
Non-crosser (deflector etc)					
2010	1	0	0	0	1
2011	0	0	0	0	0
2012	0	1	0	0	1
2013	1	2	0	0	3
2014	0	0	0	0	0
2015	0	0	0	0	0
2016	0	0	0	0	0
2017	0	0	0	0	0
2018	0	1	0	1	2
2019	0	1	0	2	3
Captured during spring migration near road					
2010	0	0	0	0	0
2011	1	3	0	1	5
2012	0	0	0	0	0
2013	0	0	0	0	0
2014	0	0	0	0	0
2015	0	1	0	1	2
2016	1	8	0	0	9
2017	0	0	0	0	0
2018	6	7	0	8	21
2019	0	0	0	0	0
Away from road (north or east)					
2010	11	0	0	0	11
2011	6	0	0	0	6
2012	6	2	0	0	8
2013	1	2	0	0	3
2014	2	3	0	0	5
2015	1	1	0	1	3
2016	2	2	0	4	8
2017	1	8	0	5	14
2018	0	0	0	0	0
2019	4	3	0	1	8

7.4 Details of spring migration model selection

Model selection was undertaken using a hierarchical approach. First, univariate analyses were conducted for each covariate grouping to assess relative strengths of association. Second, the most supported models from each category were combined into composite models. Of yearly variation models, a model that pooled years up to 2015 was most supported (Table 13, model 26) which was presumably due to low samples sizes of caribou prior to 2016. A model with maximum temperature at Meadowbank was the most supported of weather covariates (model 20). Other weather covariates, such as temperature at Baker lake, which were correlated with the Meadowbank temperature were less supported and are now shown. For habitat covariates, lake distance was most supported (model 14), however it was suspect this might be related to distances from road as well as side of road and therefore other habitat covariates were considered in composite models. In terms of caribou, the side of the road (prior to crossing to the west or after crossing to the east) was much more supported than other covariates (model 10), however it was likely that this covariate was also related to road effects, and therefore, other covariates such as ELC and Ice, were considered in composition models.

For composite models, the EW term and YearP15 (years prior to 2015 were pooled) terms were immediately added given their relative high support as well as likely yearly variation in movement rates (Model 7). The main habitat covariates were then added to the EW + YearP15 model with a model using an ELC term being most supported (model 5). The weather covariate, Temp Max, was then added with lower support of the model (model 9). This was potentially due to the larger number of parameters in the ELC model and therefore an ice model was considered, which is a reduced version of the ELC model (Model 1) which did have higher support and was the most supported of models considered.

The YearP15+EW+TempMax+Ice model was used as a base model for ZOI models (Table 3 in main report). Some covariates, such as CapYear (Capture Year), were considered further in the context of the ZOI analysis as detailed in the main body of the report.

Table 13. Detailed model selection results for spring migration analysis. Akaike Information Criteria (AIC_c), the difference in AIC_c values between the *i*th and most supported model 1 (ΔAIC_c), Akaike weights (w_i), number of parameters (*K*), and log-likelihood (LL) are presented.

No	Model	AICc	ΔAICc	Within-group ΔAICc	K	wi	LL
	Composite (Multi-covariate) models						
1	YearP15+EW+TempMax+Ice	50357.8	0.48	0.48	8	0.97	-25168.9
2	Year+EW+TempMax+Ice	50364.0	6.76	6.76	11	0.03	-25167.1
3	YearP15+EW+TempMax	50379.9	22.63	22.63	7	0	-25181.5
4	YearP15+EW+ELC	50519.8	162.54	162.54	11	0	-25245.0
5	YearP15+EW+Ice	50525.9	168.57	168.57	7	0	-25254.5
6	YearP15+EW+ LakeDistance	50546.7	189.41	189.41	7	0	-25264.9
7	YearP15+EW	50551.7	194.47	194.47	6	0	-25268.8
8	YearP15+EW+Capyear	50554.1	196.80	196.80	7	0	-25268.6
9	YearP15+EW+TempMax+ELC	50761.5	404.25	404.25	11	0	-25365.9
	Caribou and sampling						
10	Side of road	50627.8	270.55	0	3	0	-25310.6
11	Capture year	51331.7	974.39	703.84	3	0	-25662.6
12	Fix Interval	51356.4	999.163	728.61	3	0	-25674.9
13	Herd	51356.8	999.56	729.01	5	0	-25672.7
14	Prevyear: Crossed previous year	51361.7	1004.42	733.87	3	0	-25677.6
	Habitat						
15	LakeDistance	51264.8	907.57	0.00	3	0	-25629.1
16	ELC	51318.3	961.00	53.43	7	0	-25650.7
17	Ice (ELC water class)	51319.8	962.53	54.96	3	0	-25656.6
18	Lake (Lake distance=0)	51361.9	1004.64	97.07	3	0	-25677.7
19	TRI (terrain ruggedness)	51364.7	1007.41	99.84	3	0	-25679.1
20	Elevation	51365.5	1008.26	100.69	3	0	-25679.5
	Weather						
21	TempMax (Meadowbank)	50852.8	495.47	0.00	3	0	-25423.1
22	TempAve (Meadowbank)	50895.8	538.51	43.04	3	0	-25444.6
23	JulianDay	51119.9	762.57	267.10	3	0	-25556.6
24	WindGust	51346.9	989.57	494.10	3	0	-25670.1
25	Precipitation	51366.1	1008.80	513.33	3	0	-25679.8
26	Snow	51366.1	1008.80	513.33	3	0	-25679.8
	Year						
27	YearP15 (year<2016 pooled)	51300.6	943.28	0.00	5	0	-25644.5
28	Year	51305.5	948.26	4.98	8	0	-25642.8
29	YearP16 (year<2018 pooled)	51329.1	971.87	28.59	4	0	-25660.1
	Intercept only						
30	Intercept only	51363.8	1006.51		2	0	-25679.8

7.5 Detailed BCRW results

Table 14 summarizes the complete BCRW analysis results by collar.

Table 14. Observed and expected crossing times (in days) for spring migration. Slow crossers (expected mean >) are indicated in bold. Crossing times that are significantly different from the mean are indicated with an asterix (*).

Collar	Observed	Expected	Delay	Collar	Observed	Expected	Delay
BL0430411_2011	3	4	-1	BL0730416_2018	2	3	-1
BL0360411_2011	2	2	0	**BL2018017_2018**	**2**	**1**	**1**
BL0340411_2011	2	2	0	**BL0600415_2018***	**6**	**3**	**3**
BL0310411_2011	3	3	0	**BL0690416_2018***	**6**	**3**	**3**
BL0420411_2011	**3**	**2**	**1**	**BL0670415_2018***	**10**	**3**	**7**
BL0390411_2011	**4**	**2**	**2**	**BL2018002_2018***	**8**	**3**	**5**
BL0320411_2011	**4**	**2**	**2**	**BL0750416_2018***	**11**	**3**	**8**
BL0360411_2012	**4**	**3**	**1**	**BL2018003_2018***	**12**	**3**	**9**
BL0380411_2012	**4**	**3**	**1**	**BL201733_2018***	**7**	**2**	**5**
BL0540413_2013	2	2	0	**BL2018010_2018***	**13**	**2**	**11**
BL0520413_2013	**3**	**2**	**1**	**BL2018011_2018***	**12**	**2**	**10**
BL0640415_2015	2	3	-1	BL2018010_2019	1	1	0
BL0590415_2015	2	2	0	BL2018014_2019	2	3	-1
BL0600415_2015	**4**	**2**	**2**	BL2018011_2019	2	3	-1
BL0680415_2015	**5**	**3**	**2**	BL0680415_2019	4	4	0
BL0670415_2015	**9**	**4**	**5**	BL0640415_2019	4	2	2
BL0620415_2016	1	2	-1	**BL201709_2019**	**7**	**4**	**3**
BL0640415_2016	2	2	0	**BL201724_2019***	**9**	**3**	**6**
BL0680415_2016*	**6**	**2**	**4**	**BL0600415_2019***	**8**	**3**	**5**
BL0600415_2016*	**12**	**3**	**9**	**BL2018024_2019***	**9**	**3**	**6**
BL0760416_2018	4	6	-2	**BL2018054_2019***	**14**	**2**	**12**

7.6 Sensitivity of results to live capture efforts in 2018

Live capture of caribou for collaring occurred in 2011,2013, 2015, 2016, and 2018 (Table 14). Caribou that were captured in the proximity of the road (<20 km from the road) or on the far (east side) of road after crossing, were not included in analyses for the given year. This approach still allowed a smaller subset of caribou that were captured away from the road to contribute to the analysis. If all caribou captured during the year of the study were excluded, sample sizes would be reduced to less than 10 caribou except for 2019, and based on this reports analysis, could not be justified.

Table 15. Summary of live capture for collaring efforts.

Year	Live captures			Caribou available for analysis	
	total	Excluded (<20 km)	Included (>20 km)	Available	Available if no live captures included
2010	0	0	0	0	0
2011	12	5	7	7	0
2012	0	0	0	2	2
2013	2	0	2	3	1
2014	0	0	0	0	0
2015	7	2	5	5	0
2016	9	9	0	5	5
2017	0	0	0	0	0
2018	27	21	6	13	7
2019	0	0	0	11	11
totals	57	37	20	46	26

Of most interest are captures that occurred in 2018 when substantial deflections of collared caribou were detected around the Meadowbank roads (Figure 34). Capture efforts occurred on April 30, May 1st and May 2nd on both the east and west side of the road. In total, 27 caribou were collared of which only 6, captured from 31 to 65 km from the road, were used in the analysis. These caribou were captured at least 30 km from the road (mean=45.5km, std. dev=15.5, min=31.4km, max=64.km, n=6).

We suggest there are two potential effects of live capture. First there was a potential capture related change in the ΔD_{mine} metric as discussed previously. Second, the caribou that were live captured may have exhibited more aversive behaviour to the road due to the previous live capture experience. The effect of live capture on movements was partially tested in the main analyses using a capture year covariate which allowed caribou captured to have different mean movement rates than other caribou in the analysis. In addition, specific zones of influence were tested for caribou during the year of capture and other caribou captured in previous years (Table 3, model 6). The analyses in this section further test the sensitivity of results to capture efforts in 2018 by eliminating the dates of the capture from the analysis completely and further modelling the capture effects. In addition, analyses that eliminate all caribou captured in 2018 are considered, however, results are limited by sample sizes available (n=7 caribou) for this exercise.

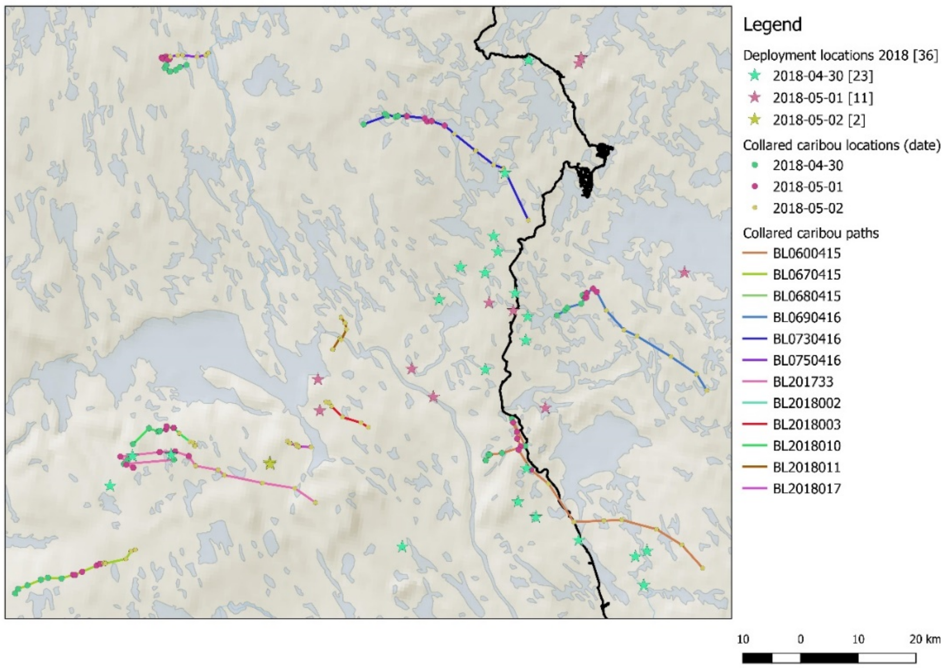

Figure 34. Deployment locations by date for 2018 capture efforts along with paths of collared caribou during the April 30 to May 2nd interval in which live capture occurred.

7.6.1 Change in movement rates after capture

One of the immediate questions regarding live capture is whether caribou displayed increased or decreased movement rates relative to the mine road after live capture. Plots of daily ΔD_{mine} rates for caribou captured > 20 km from the road do not show large-scale differences in movements of caribou after the 2018 live capture (caribou with red lines in Figure 35). Potential exceptions are BL201733 and BL201811, which show a potential increase in ΔD_{mine} up to 3 days after capture. The time period between live capture and road crossing was at least a week for all live capture caribou except BL2018017, which was not delayed by the road (estimated delay = 0 days). A reduction of ΔD_{mine} occurred for most caribou (that had delays > 0) in the vicinity of the road for all caribou, as estimated by the ZOI.

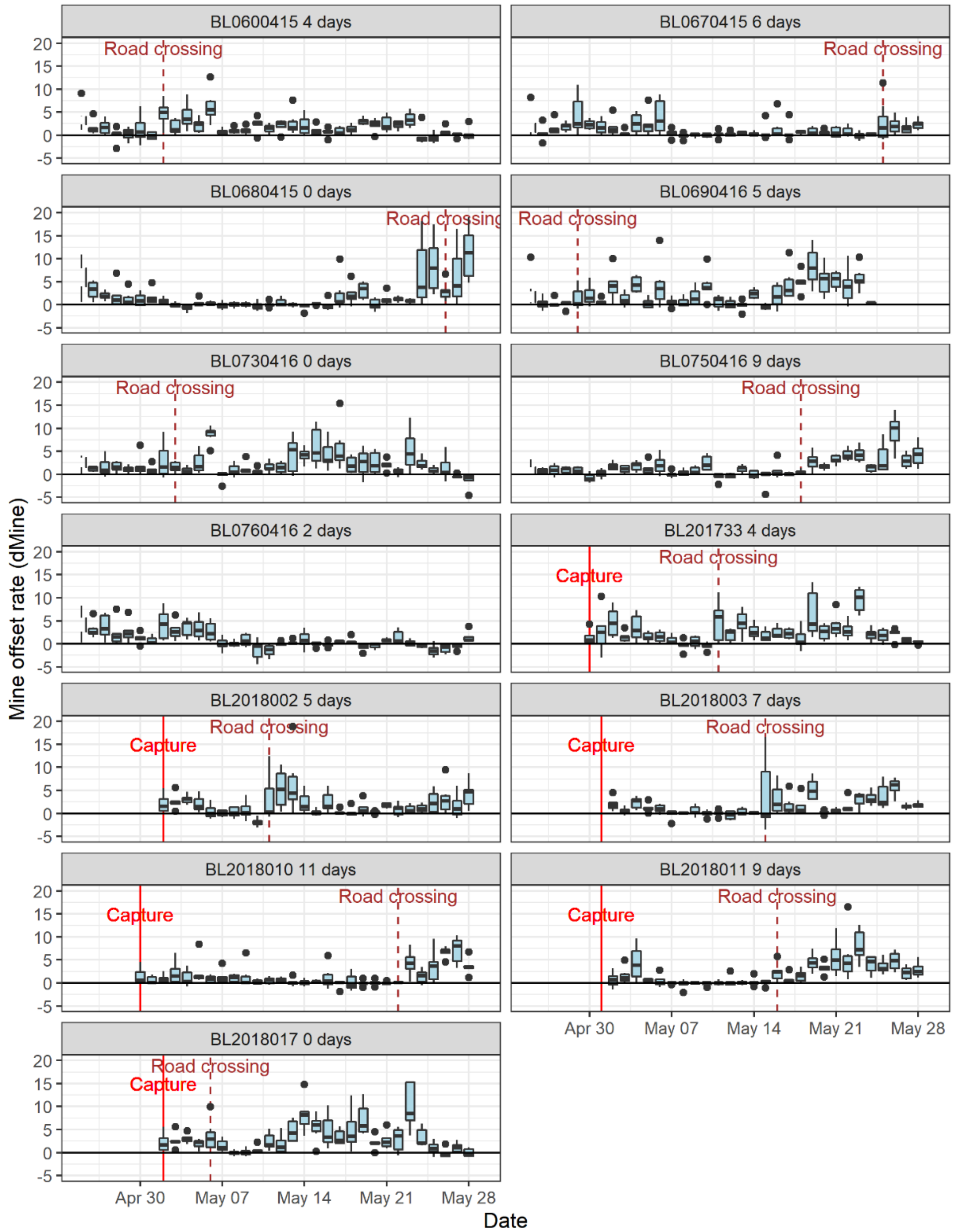

Figure 35. Boxplots of mine offset rates (ΔD_{mine}) for caribou captured in 2018 (caribou with red line in plot that delineates date of capture and caribou not captured in 2018. The date of road crossing is delineated by a hatched brown line. The number of days that a caribou was estimated to be delayed by the road is given after each caribou id.

Mine offset rate (ΔD_{mine}), which was the primary response variable for analyses, is the most applicable to determining whether capture effects analyses. Overall, response to capture might also be gauged by movement rate, which will not be influenced by the road. Figures 36 and 37 display movement rates after capture based upon 4 hour interval fixes. A LOESS smoothing trend line is fitted to each set of points to assess directional trends in movement rate. Figure 34 displays caribou included in the analysis, including caribou that were live captured prior to 2018. Caribou captured prior to 2018 (i.e. BL0680415) as well as caribou captured in 2018, show smaller-scale directional trends in movement rates. Movement rate often increases in the proximity of the road as discussed previously in the report (Figure 13).

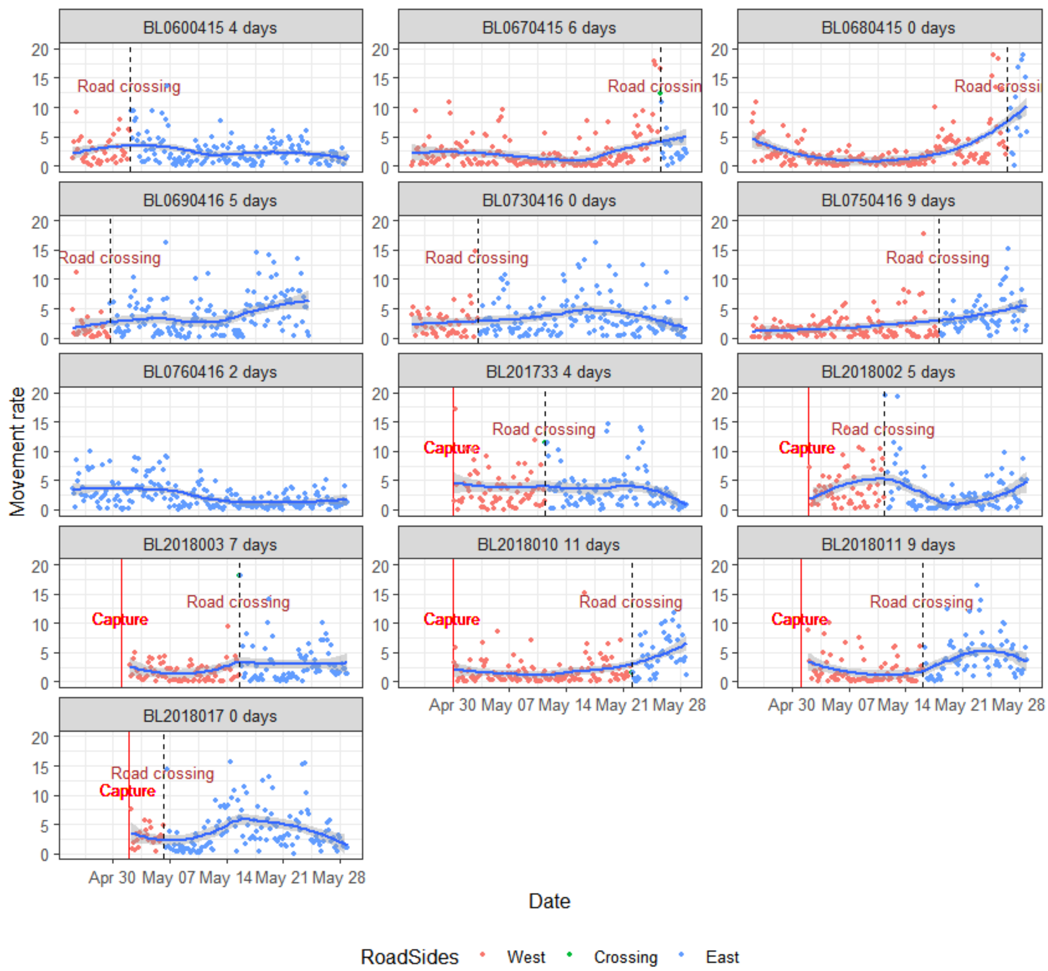

Figure 36. Scatterplots of movement rate for caribou captured in 2018 (caribou with red line in plot that delineates date of capture), and caribou not captured in 2018 that were included in the analysis. The date of capture is delineated if a caribou was captured in 2018 and the date of road crossing is delineated by a hatched line (if the caribou crossed the road within the date range displayed). The number of days that a caribou was estimated to be delayed by the road is given after each caribou id.

Of the caribou captured in 2018, 21 were not used in the analysis due to capture <20 km from the road or capture after crossing the road. Figure 35 displays the movement rates of these caribou as a function of days after live capture. A few caribou display increased movement rates after capture (BL201803), however in most cases the change was not significant.

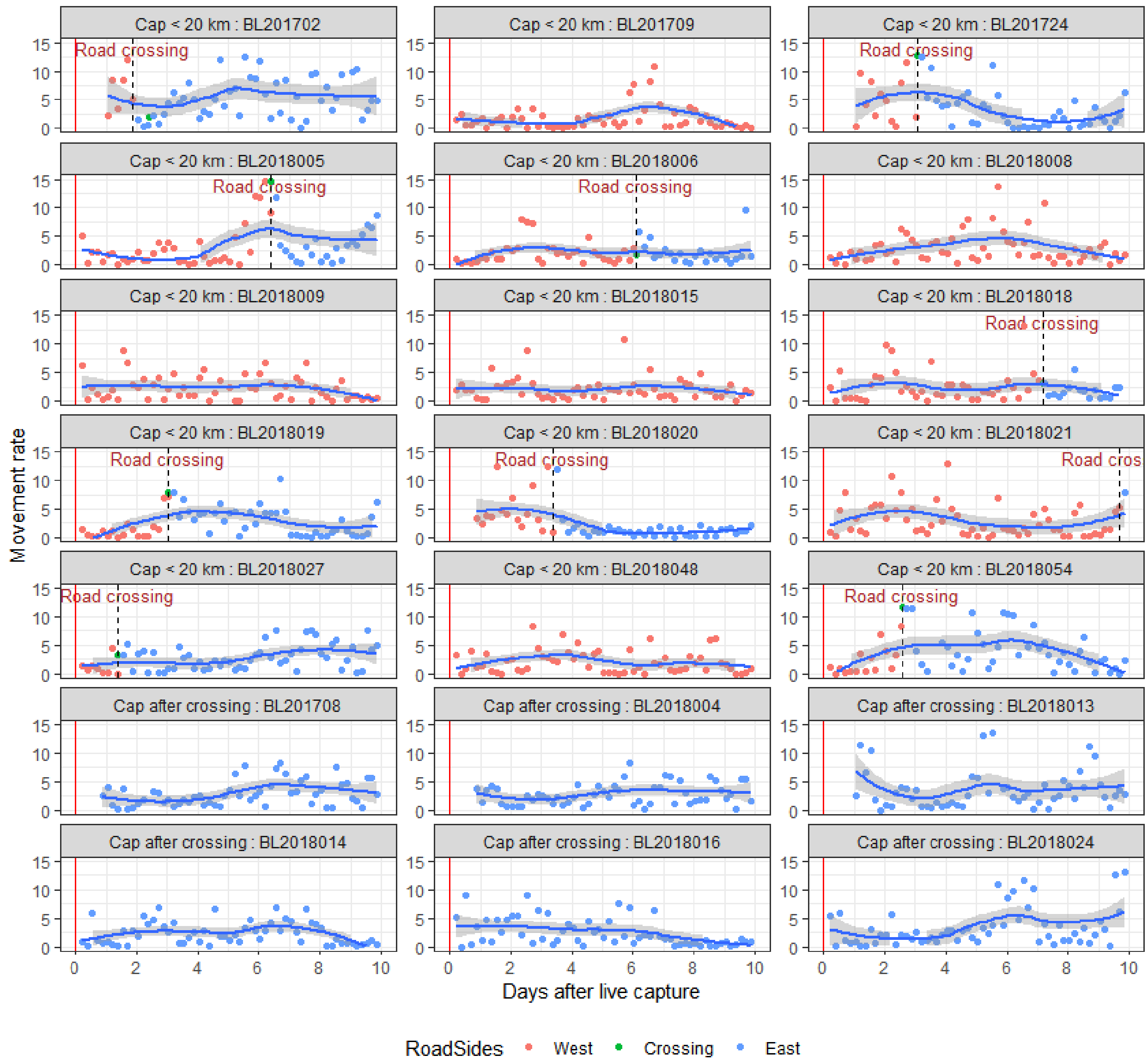

Figure 37. Scatterplots of movement rates for caribou captured in 2018 (red line in plot delineates date of capture) not included in the analysis (due to capture after crossing the road or capture<20 km of road) by days after live capture. The live capture (at day 0) is delineated by a red line and road crossing by a hashed line for caribou captured prior to crossing the road.

7.6.2 *Sensitivity of analysis results to 2018 live capture*

This section presents sensitivity analysis to live capture efforts in 2018. The primary analyses conducted first removed the dates that live capture occurred to determine if movements of collared caribou (both captured in 2018 and captured previous to 2018) were affected. Second, analyses results were run with caribou captured in 2018 completely removed from the analysis along with the capture dates. Overall, sensitivity analysis suggests minimal sensitivity if the dates of live capture are removed from analyses. If all collared caribou captured in 2018 are removed from the data set the sample size of available caribou is reduced to 6 caribou which challenges estimation of model parameters due to smaller sample size.

7.6.2.1 Zone of influence estimates

Table 16 shows terms from the most supported ZOI model with dates of live capture (April 29- May 1 2020 removed). All terms remained significant suggesting that inclusion of the dates of live capture did not affect analysis results appreciably.

Table 16. ZOI model estimates when dates of live capture are removed.

Parameter	Beta	Std. Err	Wald Z	P-value
Base terms				
(Intercept)	27.45	1.07	25.65	0.0000
Year(2018)	-4.80	0.41	-11.79	0.0000
Year(2019)	-5.39	0.42	-12.70	0.0000
TempMax	0.26	0.02	13.90	0.0000
Ice	2.57	0.51	5.05	0.0000
ZOI slope terms				
East side of road (crossed): all years	-3.14	1.22	-2.58	0.0098
West side of road (not crossed): 2018	-0.31	0.11	-2.87	0.0041
West side of road (not crossed): 2019	-0.37	0.08	-4.82	0.0000

ZOI of the road was significant, as indicated by confidence limits that did not overlap 0 for both the east and west side of the road (Table 17). Zone of influence estimates for 2018 were slightly reduced compared to the full data set, however, the difference was negligible.

Table 17. Estimates of zone of influence for caribou prior to crossing (west side of road) and after crossing (East side of road) from model 1 when date that live captured occurred are not used in the analysis.

Side of road	ZOI	Std. Err.	Wald Z	P-value	CI low	CI high
East side of road (crossed): all years	-2.98	1.48	-2.01	0.044	0.07	5.89
West side of road (not crossed): 2018	-12.85	5.06	-2.54	0.011	2.93	22.77
West side of road (not crossed): 2019	-15.74	5.46	-2.88	0.004	5.04	26.44

In the main analysis (Table 3: Model 6), a model with specific ZOI terms for caribou live captured in 2018 was not supported as indicated by AICc model selection suggesting that caribou that were live captured did not have statistically different ZOI's than caribou not live capture in 2018. The analysis was rerun with all the caribou captures in 2018 eliminated from the data set along with dates of live capture, which reduced the yearly sample size of caribou in 2018 to 7 caribou (Table 18).

Table 18. ZOI parameter estimates when caribou captured in 2018 are eliminated from the analysis.

Parameter	Beta	Std. Err	Z	p-value
<u>Base terms</u>				
(Intercept)	27.11	3.18	72.78	0.0000
Year (2018)	-4.72	1.36	12.11	0.0005
Year (2019)	-4.98	1.07	21.53	0.0000
TempMax	0.28	0.05	37.18	0.0000
Ice	2.26	0.70	10.52	0.0012
<u>ZOI terms</u>				
East side of road (crossed): all years	-2.79	1.35	4.29	0.0383
West side of road (not crossed): 2018	-0.43	0.29	2.17	0.1404
West side of road (not crossed): 2019	-0.35	0.17	4.31	0.0380

The estimate of zone of influence estimate for 2018 from was 9.5 (Table 19) when all caribou live captured in 2018 were removed from the data set. Estimate precision was reduced likely due to low sample sizes (n=7 caribou). The zone of influence estimate for 2019 as well as the zone of influence after crossing, were minimally affected.

Table 19. Estimates of zone of influence when caribou captured in 2018 and live capture dates in 2018 eliminated. The resulting sample size for 2018 was 7 caribou.

Side of road	Est.	Std. Err.	Wald Z	P-value	CI low	CI high
East side of road (crossed): all years	3.06	1.52	-2.014	0.044	0.08	6.04
West side of road (not crossed): 2018	9.5	6.07	-1.569	0.117	-2.37	21.41
West side of road (not crossed): 2019	16.3	6.18	-2.643	0.008	4.22	28.45

7.6.2.2 Estimates of delay

The most direct method to assess the effects of live capture on delay in migration due to encounter with the road is to stratify the delay estimates by whether a caribou is captured in the given year or previous year (Figure 38). These results suggest that estimates of delay are above 0 for 2018 for caribou captured in the previous or current year, and both groups have higher mean estimates of delay than 2019. This result suggests that the effect of live capture on estimates of delay is not large.

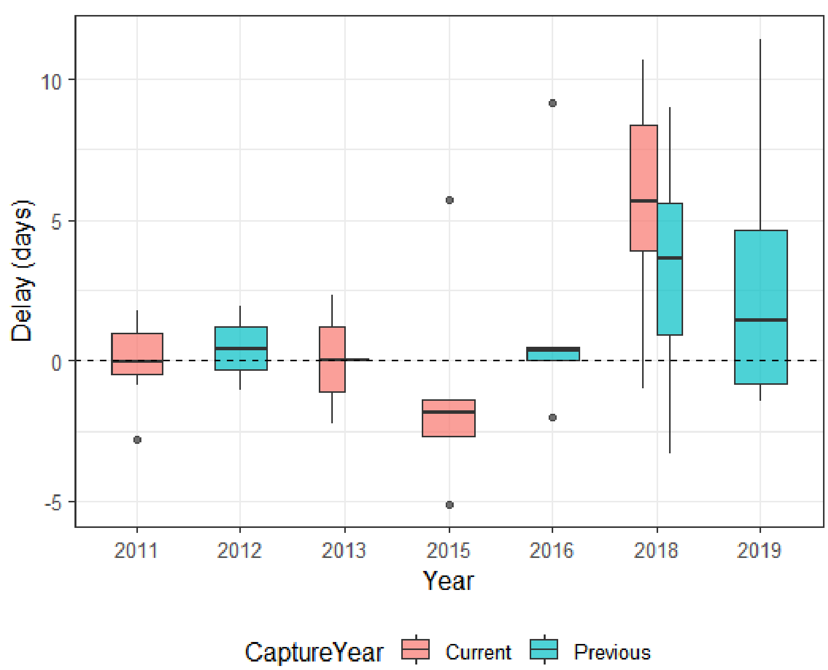

Figure 38. Estimates of delay stratified by whether a caribou was live captured in a previous year or current year.

7.6.2.3 Road crossing analysis

The road crossing analysis was rerun with the live capture dates removed, with the interaction of distance from road and caribou captured in 2018 as an interaction term, and with the caribou captured in 2018 removed. The magnitude of the road closure effect was significant regardless of analysis type. An interaction term of capture X distance from road was significant suggesting that caribou captured in 2018 displayed a higher crossing probability than caribou not captured in 2018. However, they did not show a significantly different response to road closure (as indicated by the Road closed X dist from road term), suggesting that the overall effect of road closure was similar for caribou captured in 2018 and other caribou in the analysis. If all caribou captures in 2018 are eliminated, the road closed term is still significant, however, its magnitude is reduced, a finding that is consistent with reduced sample size. It is difficult to confirm if this is due to the substantive reduction in sample size of caribou (n=13 from n=19) or other effects (Table 20).

Table 20. Sensitivity of road crossing analysis to live capture in 2018.

Parameter	Estimate	SE	Z	p-value
Full data set (n=19 caribou)				
Road closed	4.53	1.02	4.46	0.000
Road open X dist from road	-0.05	0.10	-0.48	0.634
Road closed X dist from road	-4.43	1.21	-3.64	0.000
Live capture dates removed (n=19 caribou)				
Road closed	4.24	1.02	4.15	0.000
Road open X dist from road	-0.02	0.10	-0.23	0.816
Road closed X dist from road	-4.55	1.35	-3.36	0.001
Modelling caribou that were captured in 2018				
Road closed	4.67	1.29	3.61	0.000
Road open X dist from road	-0.55	0.19	-2.97	0.003
Road closed X dist from road	-4.93	1.42	-3.46	0.001
CaptureYear X dist from road	0.79	0.22	3.64	0.000
CaptureYear X Road closed	-0.21	1.55	-0.13	0.895
Eliminate caribou captured in 2018 and live capture dates (n=13 caribou)				
Road closed	2.96	1.37	2.16	0.030
Road open X dist from road	-0.79	0.23	-3.46	0.001
Road closed X dist from road	-3.04	0.98	-3.12	0.002

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