APPENDIX C - Evaluating the effect of the construction of the Tłı̨chǫ ASR on boreal caribou movements

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Abstract

As required under the Tłı̨chǫ ASR WMMP, we assessed the impacts of the construction of the Tłı̨chǫ ASR on movement behaviour of boreal caribou. The road was constructed from September 2019 to November 2021, with caribou data also available for the pre-construction period from March 2017 to September 2019. Using location data from GPS-collared caribou, we mapped where boreal caribou crossed the Tłı̨chǫ ASR alignment before and during construction, and compared crossing rates between the two time periods, accounting for differences in monitoring efforts. We used piecewise regression analysis to estimate breakpoints in caribou movement characteristics (step lengths and turn angles) as a function of distance to road and used generalized additive models to evaluate how movements changed with distance to road, allowing for a more flexible response. We then used an integrated step-selection analysis to quantify how caribou changed their movements and habitat use near roads, accounting for variation among individuals and for habitat preferences. We also compared caribou movements around the Tłı̨chǫ ASR, before and during construction, to caribou movements around Highway 3, which connects the Tłı̨chǫ ASR to the NWT highway system. We found consistent results across these methods. Boreal caribou crossed the Tłı̨chǫ ASR much more frequently than Highway 3, which was rarely crossed, but caribou moved more quickly when crossing the Tłı̨chǫ ASR than when moving elsewhere on the landscape. Boreal caribou crossed the Tłı̨chǫ ASR alignment both before and after construction, although crossing rates decreased during the pre-calving season after construction began (controlling for effort). During the construction period of the Tłı̨chǫ ASR, caribou moved faster and straighter when they were closer to the road. This effect differed from the pre-construction period, when proximity to the road had no effect on caribou changes in direction and only a small effect on movement speed. This effect was consistently observed and was significant, when controlling for individual and for habitat. Caribou behaviour near the Tłı̨chǫ ASR also showed fewer quick cross events and more bounce events (getting close to the road then quickly moving away without crossing) during the construction period compared to before construction. This was consistent across all seasons except pre-calving, when there were few encounters to assess during the construction period. Overall, this work provides insight into how caribou behavior was affected by construction of the Tłı̨chǫ ASR. The WMMP requires additional analyses after the Tłı̨chǫ ASR is operational for five years, which will provide further insight into the impact of an active all-season road on boreal caribou movements.

Introduction

The Tłı̨chǫ ASR is a new all-season road that connects the community of Whatì to Highway 3, approximately 30 km southwest of Behchokǫ̀, and is in the Wek'èezhìı Management Area of the Northwest Territories. The GNWT began construction of the Tłı̨chǫ ASR on September 3, 2019, and completed construction on November 20, 2021. The completed Tłı̨chǫ ASR largely follows an old overland winter road alignment to Whatì that was used up until the late 1980's (Golder Associates Ltd. 2017). Under the *Mackenize Valley Resource Management Act*, an EA by the Mackenize Valley Environmental Impact Review Board (EA1716-01) was required before this project was approved. Under Measure 10-2 of MVEIRB's Report of EA for the Tłı̨chǫ ASR, and under s.95(1) of the *Wildlife Act,* a WMMP for the Tłı̨chǫ ASR was required. WMMPs describe how developers will minimize impacts to wildlife and wildlife habitat from their project and thus remain in compliance with regulatory requirements and address public concerns. WMMPs are reviewed and reported on annually. The Tłı̨chǫ ASR WMMP section 6.1.3 required that comprehensive analyses of wildlife mitigation and wildlife effects monitoring be done after road construction was completed, including addressing specific questions about the effect of the road on boreal caribou. The corresponding analyses are reported here.

In November 2020, the GNWT and Tłı̨chǫ Government announced the official name of the new Tłı̨chǫ ASR would be the Tłı̨chǫ Highway, or Highway 9. Because this report addresses the pre-construction and construction phases of the road, and for consistency with the WMMP and the Construction Phase Comprehensive Report, we refer to the pre-construction alignment, and the road under construction, as the Tłı̨chǫ ASR throughout this report.

To understand if construction of the Tłı̨chǫ ASR affected boreal caribou movements, we compared boreal caribou movements near the Tłı̨chǫ ASR alignment before construction to caribou movements in the same area during the construction period. GPS collars were deployed on boreal caribou in the vicinity of the Tłı̨chǫ ASR alignment 2.5 years prior to the start of construction and provided a baseline of caribou movements in the proposed area before construction. We also compared boreal caribou movements near Highway 3 to caribou movements near the Tłı̨chǫ ASR. Existing collar data suggested that Highway 3 did affect boreal caribou movements, with few collared caribou crossing Highway 3. We included Highway 3 in some analyses to verify that the methods used would be able to detect impacts of a linear feature on boreal caribou, even if no impacts of the Tłı̨chǫ ASR were detected during the construction period.

Objectives

Our objectives were to:

1) Determine if boreal caribou movement behaviors (e.g. step lengths, turning angles) change with the proximity of caribou to roads (before and during construction) and
2) Determine if boreal caribou movement behaviour types changed when encountering different road types (the Tłı̨chǫ ASR before construction, Tłı̨chǫ ASR during construction, and Highway 3).

Study Area

Tłı̨chǫ All-Season Road

The Tłı̨chǫ ASR is a 97-km road that connects Whatì to Highway 3, approximately 30 km southwest of Behchokǫ̀ (Figure 2-1 in *Comprehensive Wildlife Management and Monitoring Plan Report for the Construction Phase of the Tłı̨chǫ All-Season Road*). As built, the Tłı̨chǫ ASR is a two-lane gravel road with an 8.5 m wide road surface and a maximum 60 m wide cleared RoW (including the 8.5 m road surface). The road starts at KM 196 on Highway 3 and extends to the Community Government of Whatì boundary, partially following an old winter alignment (i.e., the Old Airport Road). An all-season community road is present from the municipal boundary of Whatì, where the Tłı̨chǫ ASR ends, to community infrastructure within Whatì.

The GNWT began construction of the Tłı̨chǫ ASR on September 3, 2019. During construction, six borrow source locations and 1 camp area were used to provide appropriate fill for the road construction. Road construction progressed to KM 45 (geotextile placement) by the end of 2019, although vegetation clearing took place up to KM 54 and pioneering occurred up to KM 85. In 2020, construction activities occurred up to KM 97 (i.e., end of the project). Road construction was completed on November 20, 2021, and the road opened to the public on November 30, 2021. The road was closed to the public during the construction phase. During the EA process, the predicted annual average vehicular traffic on the road was estimated to be 20 – 40 vehicles per day, including potential traffic from a proposed mine north of Whatì.

Old Airport Road to Whatì

The Tłı̨chǫ ASR alignment followed, where feasible, a pre-existing linear feature known as the Old Airport Road, likely named after a historic airstrip (circa 1940s) near the junction of the Tłı̨chǫ ASR and Highway 3. The first 20 km or so of the Tłı̨chǫ ASR alignment area has been easily accessed from Highway 3, and used for decades for timber harvesting and other uses. After this point travel was more difficult, but it was possible to get as far as the La Martre River by quad. People would also occasionally travel out of Whatì by snowmobile on parts of the Tłı̨chǫ ASR alignment, in early winter before the winter road from Whatì to Behchokǫ̀ opened up for the season (L. Lewis, pers. comm. 2023). Before construction of the Tłı̨chǫ ASR started, geotechnical drilling and surveying to determine the optimal road alignment was done over several years (T. Brooks, pers. comm. 2023). Thus, there was an existing linear feature for part of the alignment, and some human activity in the area, that caribou may or may not have responded to before the construction phase of the Tłı̨chǫ ASR.

Highway 3

To detect impacts of roads on boreal caribou more broadly, we included Highway 3 in some analyses. Highway 3 is a paved all-season highway that provides access to the Tłı̨chǫ ASR and connects Yellowknife to Highway 1 just south of the Mackenzie River. It is the only road connecting Yellowknife to southern Canada. From 2017 to 2021, the average annual daily traffic on Highway 3 at KM 175 (21 km south of the Tłı̨chǫ ASR junction) was 380, 260, 210, and 190 vehicles per day for 2017, 2018, 2019, and 2020, respectively. Averaged across 24 hours, these traffic volumes correspond to a range of 8-16 vehicles per hour, although traffic is known to vary by time of day. The peak summer average daily traffic at the same location for June, July, and August was 520 vehicles in 2017 and 2018 and 230 vehicles in 2019 and 2020, or an average of 10-22 vehicles per hour.

Boreal Caribou Monitoring Program (Tłı̨chǫ ASR-NSR Caribou Study Area)

The Tłı̨chǫ ASR-North Slave Region [NSR] boreal caribou monitoring program began in 2017 in anticipation of the construction of the Tłı̨chǫ ASR. The objective of this GNWT-ECC-led program was to collect baseline boreal caribou data prior to construction and monitor the boreal caribou population in relation to the construction and operation of the new road. GPS collars (Telonics model TGW 4677-4, Mesa, Arizona) were used to provide information about the movements and habitat use of the collared caribou in relation to landscape features including the Tłı̨chǫ ASR. These collars were programmed to collect six locations per day (4-hour fix rate) and are equipped with a geofence that increases the fix rate to hourly locations when caribou are found within a buffer of 10 km from either the Tłı̨chǫ ASR alignment or Highway 3. This geofence allows for a finer-scale assessment of the behavioural response of boreal caribou to the construction and operation of the Tłı̨chǫ ASR, and to the existing Highway 3. Collars are programmed to release from caribou approximately four years after deployment. The target sample size of collars is 30 at the beginning of each monitoring year (April 1 – March 31), and additional collars are deployed annually to maintain the same size. From March 2017 to November 2021, 53 adult female caribou were fitted with GPS collars in the Tłı̨chǫ ASR-NSR study area (Figure C-1). The boreal caribou population trend was stable to increasing in this study area over the 2017-2021 period.

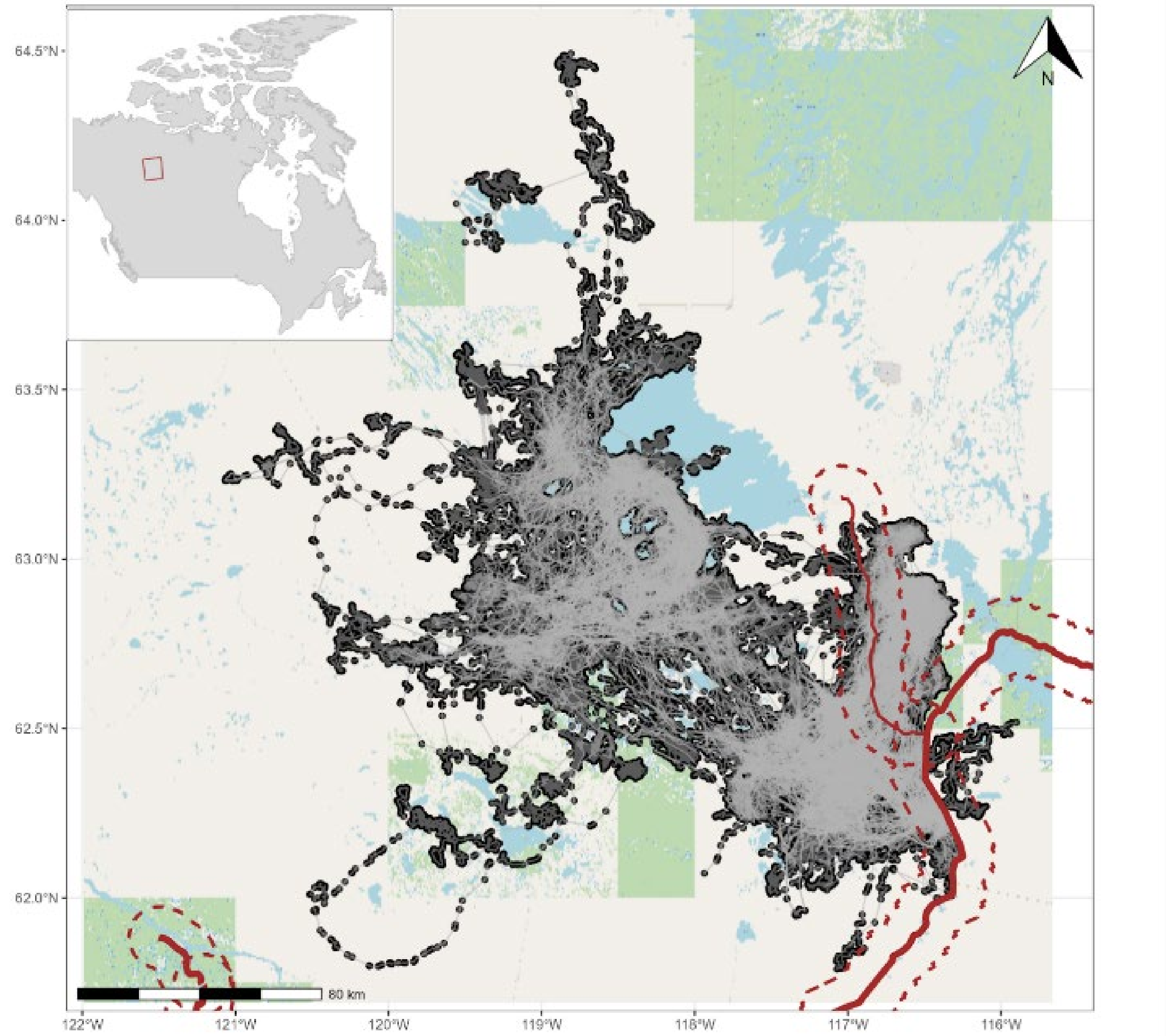

Figure C-1. Movement tracks (grey lines) and locations (black dots) of GPS-collared boreal caribou in the Tłı̨chǫ ASR-NSR study area in the NWT. The thick red line indicates Highway 3, and the dotted red lines indicate the 10 km wide geofence on either side of the of the Tłı̨chǫ ASR and Highway 3.

Caribou and Road Data

Caribou Data

Not all boreal caribou in the study area interacted with the Tłı̨chǫ ASR or Highway 3. To consider impacts of the Tłı̨chǫ ASR alignment and of Highway 3 on boreal caribou movements, we subset the caribou data to only include caribou that had at least one location within 10 km of either the Tłı̨chǫ ASR alignment or Highway 3. We included the entire trajectory of caribou locations from any individuals in this initial data subset, until the Tłı̨chǫ ASR construction phase ended (November 30, 2021). This dataset included 20 individuals before construction (mean days tracked 539 (range 170-898)) and 29 individuals after construction (mean days tracked 515 (range 130-820). Some individuals were tracked in both phases of the project (pre- and during-construction). This dataset was further subset depending on the analysis (Figure C-2).

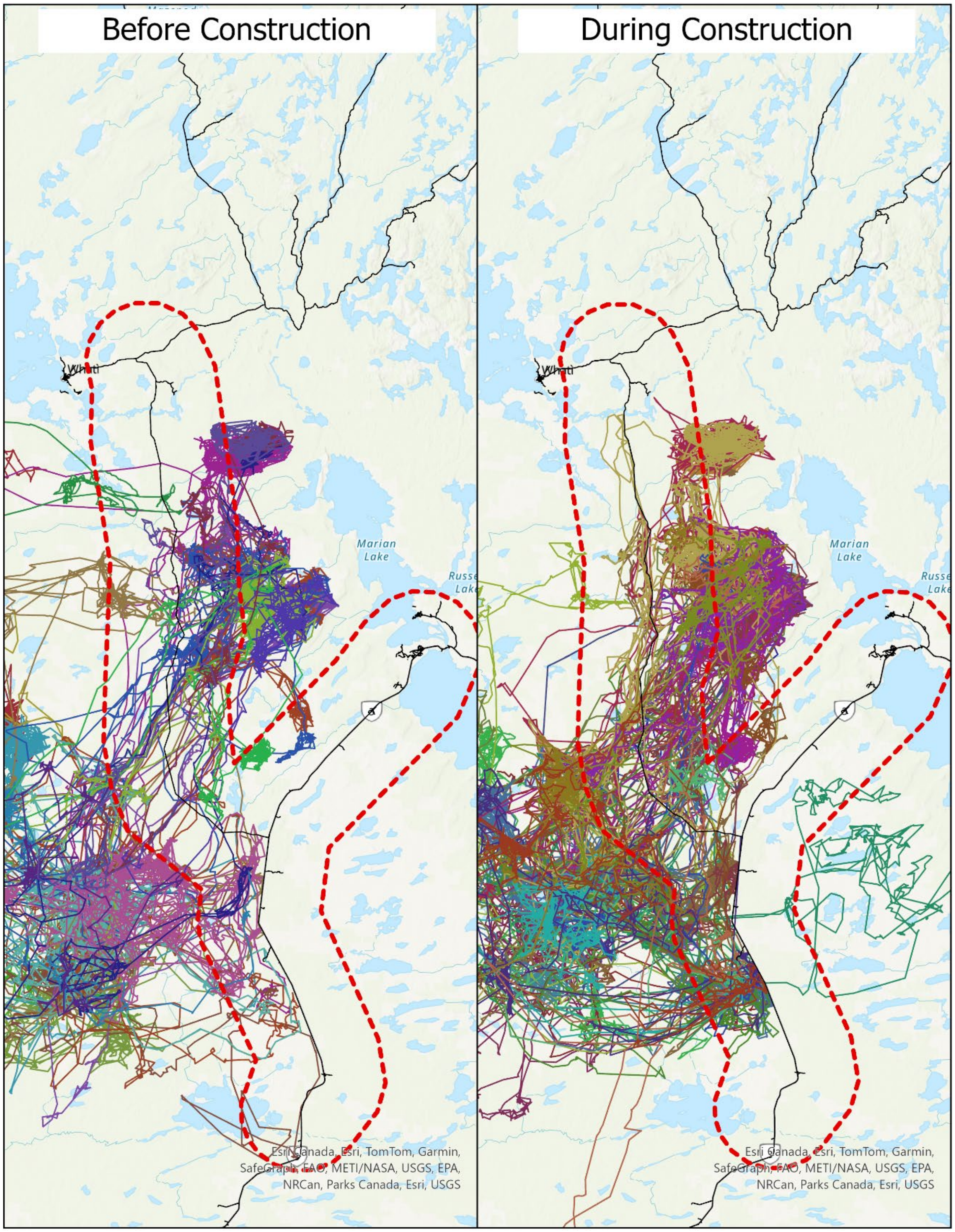

Figure C-2. Movement tracks of GPS-collared caribou filtered to individuals that interacted at least once with the 10-km geofence around the Tłı̨chǫ ASR and Highway 3 (red dotted line). Movement tracks of individual collared caribou are represented by different colored lines.

Road Data

Linear feature shape files for the Tłı̨chǫ ASR alignment and Highway 3 were obtained from the GNWT Spatial Data Warehouse (TRA_NWTCG_NWTRoads.shp).

Statistical Analyses

We conducted several analyses to evaluate the potential impact of roads (the Tłı̨chǫ ASR and Highway 3) and road construction (of the Tłı̨chǫ ASR) on caribou movement behaviors. First, we mapped where boreal caribou crossed the Tłı̨chǫ ASR, and then compared rates of road crossings for the Tłı̨chǫ ASR and Highway 3 during the two phases of the study (before versus during construction). Second, we quantified how movement characteristics (step lengths and turn angles) varied as a function of distance from road for Highway 3 and for the Tłı̨chǫ ASR before and during construction phases of the study using piecewise regression (Muggeo and Muggeo 2017; Wolfson et al. 2023) and generalized additive models (Wood 2017). Third, we fit integrated step-selection functions (Avgar et al. 2016; Fieberg et al. 2021) to quantify these same relationships, while also evaluating habitat selection as a function of distance from road. Fourth, we used barrier behaviour analysis (Xu et al. 2021) to classify caribou behaviours near roads and evaluate whether behaviour types changed between the Tłı̨chǫ ASR before versus during construction, and between the Tłı̨chǫ ASR and Highway 3.

Analysis of Road Crossing Rates

To illustrate where collared caribou most often crossed the Tłı̨chǫ ASR, we mapped the caribou movement paths within the 10-km geofence, and counted the number of times movement paths crossed the Tłı̨chǫ ASR within 1-km long road segments (Figure C-3).

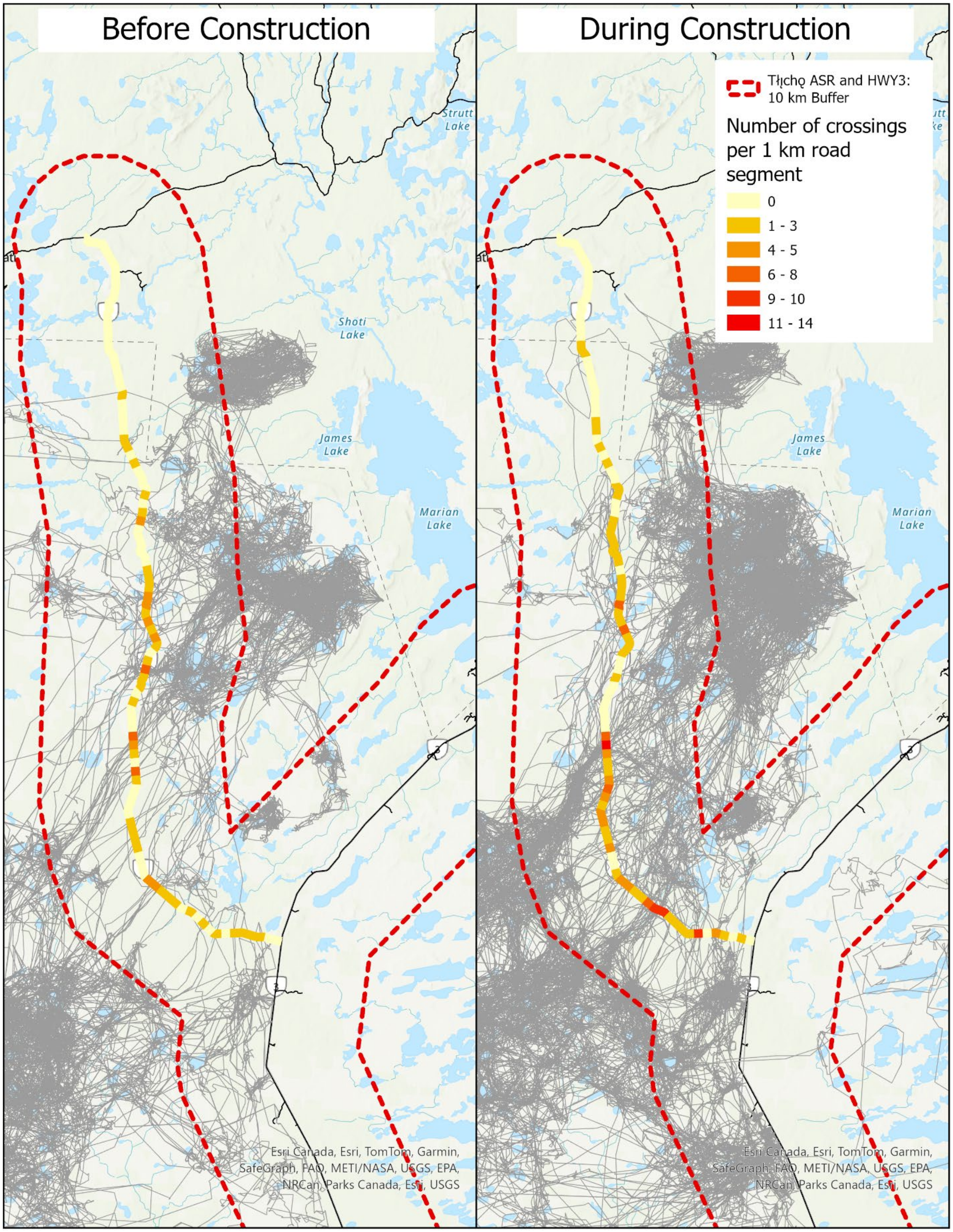

Figure C-3. Number of collared boreal caribou movement tracks (grey lines) that crossed each 1-km long segment of the Tłı̨chǫ ASR before (left) and during (right) construction.

Data Filtering and Road Crossing Indicator Variable Creation

Using the caribou location data filtered to only include observations from caribou that were observed at least once within 10 km of either the Tłı̨chǫ ASR or Highway 3, we created a dataset of "steps" joining pairs of sequential observations. We used functions in the sf package (Pebesma and Bivand 2023) to determine whether each step intersected the road, and if so, how many times the step intersected the road. If a step intersected the road an even number of times (2, 4, 6), this indicated that the step intersected a curvilinear section of road, and the animal was on the same side of the road at the start and end of the step (Figure C-4). For Highway 3, there was one step with two intersections and for the Tłı̨chǫ ASR, there were 17 steps with two intersections and one step with four intersections. In these cases, we assumed the individual never crossed the road. In addition, there were 12 steps (seven associated with Highway 3 and five associated with the Tłı̨chǫ ASR) that intersected the road, but the end of the step was very close to the road and the very next step took the animal back to the other side of the road. We assumed that these were not true road crossings, and that measurement error associated with the locations was responsible for the two sequential intersections (Figure C-3).

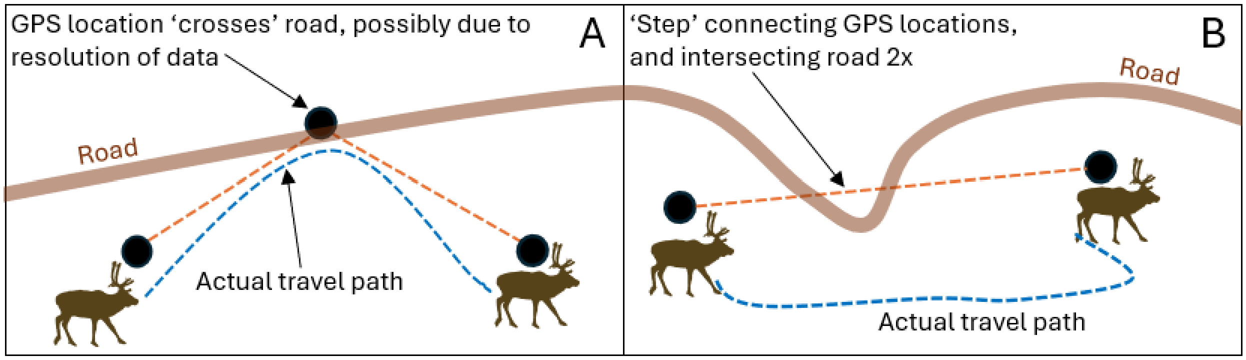

Figure C-4. Illustration of types of steps that intersected the road feature but were not considered to be true road crossings: (A) when a step intersected the road feature but was very close to the road and the sequential step 'returned' to the same side, indicating the road intersection could be due to the measurement error of the collar; (B) when a step intersected the road an even number of times, indicating the step had crossed a curved section of road and the caribou was on the same side of the road at the start and end of the step.

For each step, we calculated the step length (sl = distance between sequential locations, Figure C-7) and time between sequential observations (dt). We also calculated sl/dt as an approximation to the animal's speed of travel. We then created two datasets, one containing all steps for individuals that were observed at least once within 10 km of the Tłı̨chǫ ASR and one containing all steps for individuals that were observed at least once within 10 km of Highway 3. For the former dataset, we created a stratification variable representing the two time periods (i.e., whether steps occurred before construction (March 15, 2017 – September 2, 2019) or during road construction (September 3, 2019 – November 30, 2021)). After this data filtering, the data contained # steps from # caribou interacting with the Highway 3 geofence, # steps from # caribou interacting with the Tłı̨chǫ ASR before construction, and # steps from # caribou interacting with the Tłı̨chǫ ASR during construction.

We then plotted the distribution of sl/dt for steps that crossed and did not cross the Tłı̨chǫ ASR for the two different phases of the study (before and during road construction) (Figure C-5). Caribou clearly moved faster when crossing the road than when not crossing the road, and the effect is present in both phases of the study.

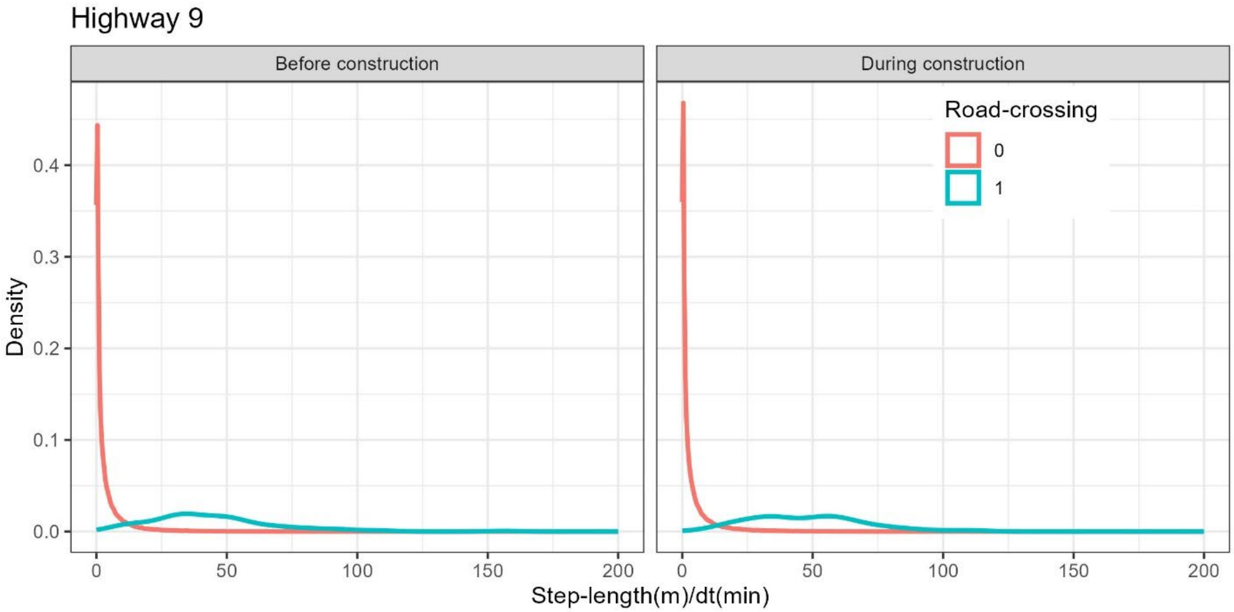

Figure C-5. Distribution of approximate speeds (step length divided by the time between successive locations, dt) for steps where caribou did ('1') or did not ('0') cross the Tłı̨chǫ ASR (Highway 9).

Effort-adjusted Crossing Rates by Season

Boreal caribou select different habitat types and have different movement rates throughout the year (e.g., DeMars et al. 2020). We created a second stratification variable representing different behavioural seasons, using the seasonal date ranges described in DeMars et al. (2020): pre-calving (April 2 – 30), calving (May 1 – July 15), summer (July 16 – September 12), early fall (September 13 – October 20), late fall (October 21 – November 30) and winter (December 1 – April 1). To account for different levels of monitoring effort during the different seasons and the two phases of the study, we determined the total number of steps, the total number of steps starting within 10 km of the Tłı̨chǫ ASR, and the total time tracked ('Time' measured in days), for each unique combination of individual ID, season, and construction phase. We also summed these variables across individuals to create a single summary measure of monitoring effort associated with each season and construction phase (Table C-1). We also calculated these same summary measures of effort for individuals located within 10 km of Highway 3 (Table C-2). We then calculated effort-adjusted crossing rates for both Highway 3 and the Tłı̨chǫ ASR (Tables C-1 and C-2). Crossing rates were an order of magnitude lower for Highway 3 than the Tłı̨chǫ ASR, regardless of the measure of effort (days tracked, number of steps) used to calculate the rate.

Table C-1. Number of times individuals crossed the Tłı̨chǫ ASR, broken down by season and construction phase, along with different measures of monitoring effort.

Season	Phase	# Crossings	Time (days)	# steps	# steps within 10 km	Crossings / 1,000 days	Crossings /1,000 steps	Crossings / 1,000 steps within 10 km
Pre-calving	Before	30	1,154	11,162	4,655	25.99	2.69	6.44
Pre-calving	During	7	1,760	15,138	2,770	3.98	0.46	2.53
Calving	Before	26	3,034	25,426	6,854	8.57	1.02	3.79
Calving	During	18	2,751	26,287	10,359	6.54	0.68	1.74
Summer	Before	2	2,163	15,990	2,745	0.92	0.13	0.73
Summer	During	5	2,280	21,128	7,393	2.19	0.24	0.68
Early fall	Before	3	795	5,692	1,266	3.77	0.53	2.37
Early fall	During	9	1,978	14,505	3,034	4.55	0.62	2.97
Late fall	Before	12	857	7,768	3,133	14.00	1.54	3.83
Late fall	During	50	2,080	20,508	10,454	24.04	2.44	4.78
Winter	Before	35	2,741	27,939	13,723	12.77	1.25	2.55
Winter	During	55	7,293	51,647	21,532	7.54	1.06	2.55

Table C-2. Number of times individuals crossed Highway 3, along with different measures of monitoring effort.

# crossings	Time (days)	# steps	# steps within 10 km	Crossings / 1,000 days	Crossings /1,000 steps	Crossings / 1,000 steps within 10 km
10	23,177	224,002	52,326	0.43	0.04	0.19

Generalized Linear Mixed Effect Model for Crossings of the Tłı̨chǫ ASR

Next, for each season, we evaluated whether the construction of the Tłı̨chǫ ASR influenced caribou crossing the road alignment. We fit a generalized linear mixed effect model to compare crossing rates by season and time period (pre-construction and during construction) for the Tłı̨chǫ ASR. We assumed, conditional on a set of random intercepts (b_i), that the number of crossings followed a negative binomial distribution with mean that varied by season, road construction phase, and their interaction:

$Y_{ijk} \mid b_i \sim$ Negative Binomial (μ_{ijk}, θ)
$\log(\mu_{ijk}) = \gamma_{jk} + b_i +$ effort variables

$$b_i \sim N(0, \sigma^2)$$

where Y_{ijk} is the number of crossings for individual i during season j (j = 1, 2, 3, 4, or 5 corresponding to pre-calving, calving, summer, early fall, late fall, and winter) and period k (k = 1, 2 for pre-construction and during construction phases), and θ is an overdispersion parameter, with $var(Y_{ijk} \mid b_i) = \mu_{ijk} + \mu_{ijk}^2/\theta$. We included log(number of steps), log(time tracked), and the number of steps within 10 km as covariates to account for differences in survey effort across the different seasons and construction phases. In addition, a random intercept for each individual was included to account for among-individual variability in crossing rates (e.g., due to variation in the location of individual home ranges in relation to the road). We evaluated fit of the model using posterior predictive checks and residual diagnostic plots from the *performance* (Lüdecke et al. 2021) and *DHARMa* packages (Hartig 2022) in R (R Core Team 2024). These diagnostic tools suggested the model provided an adequate fit to the data.

We tested for the significance of the interaction terms using the Anova() function in the *car* package (Fox and Weisberg 2019) with type II sums of squares. The p-value for this test was 0.013, so rather than simplify the model, we used the full model for inference (Fieberg and Johnson 2015). We generated model-based estimates of the number of crossings for each season during both phases of the study (pre- and during construction periods) using the empid() and ggpredict() functions in the *emmeans* (Lenth 2024) and *ggeffects* (Lüdecke 2018) packages, respectively. We also constructed a set of pairwise contrasts to test for seasonal differences in crossing rates between the two phases of the study (before versus during construction), controlling the familywise error rate using Tukey's honest significant difference (Tukey 1949).

Results

We found that crossing rates in the pre-calving season were higher before versus during construction phase of the study (Figure C-6; p-value = 0.002). We did not detect differences in crossing rates (before versus during construction) for the other seasons.

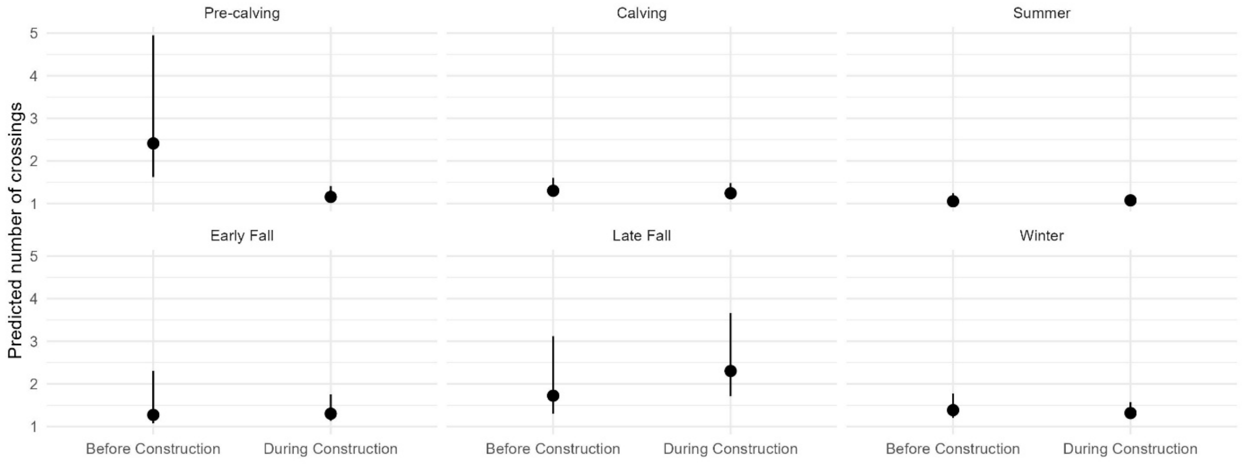

Figure C-6. Estimated number of crossings during each season and construction period for a "typical" individual (i.e., one with random intercept = 0; Fieberg et al. (2009)). All other variables were set to their mean values (number of steps = 504, days tracked = 60, and number of steps within 10 km of the Tłı̨chǫ ASR = 33). Lines depict 95% confidence intervals formed by first calculating a confidence interval on the log scale under a normality assumption and then exponentiating the confidence limits.

Summary

In summary, crossing rates of the Tłı̨chǫ ASR were an order of magnitude larger than that of Highway 3 (Tables C-1 and C-2), yet caribou moved more quickly when crossing the Tłı̨chǫ ASR than when moving elsewhere in the landscape (Figure C-5). We also detected a reduction in the number of crossings (during construction versus the pre-construction phase of the study), but only in the pre-calving period (Figure C-5).

Effect of Distance from Road on Movement Characteristics (step lengths and turn angles)

We used multiple methods (piecewise regression model, generalized additive model, and integrated steps-selection analysis) to address whether boreal caribou movements changed in proximity to the road during the construction phase. Location data from GPS collars reveal how far individual caribou move, and their direction of movement, over the time period between GPS locations. We hypothesized that as individual caribou approached a road, they would respond with a marked change in their movement that should be reflected by the step-length and turn-angles of their "steps", i.e., joined pairs of sequential observations.

Data Filtering and Processing Steps

We filtered the "steps" data sets from the road crossing analysis to only include steps where the time between successive locations was 1 hour +/- 10 minutes. This excluded any steps that started outside of the 10 km geofences for Highway 3 and the Tłı̨chǫ ASR, because locations were collected every four hours outside of the geofences. It also excluded any steps inside the geofence that were two or more hours apart due to missing GPS transmissions.

For each step, we calculated step length (sl = the straight-line distance between pairs of sequential GPS observations) and the turn angle (ta = the change in direction between two consecutive steps (Figure C-7).

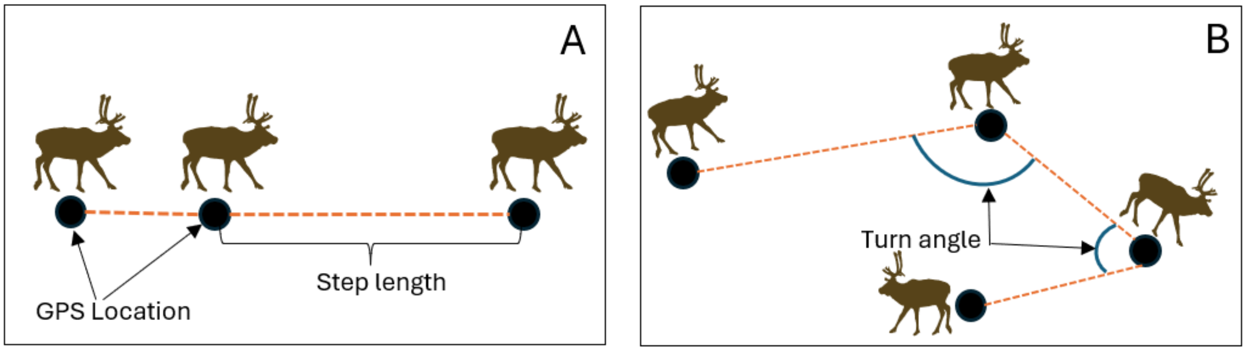

Figure C-7. Illustration of step length (the straight-line distance an animal moves between two consecutive GPS points) and turn angle (the change in direction an animal makes between two consecutive step lengths).

We then calculated log(sl) and cosine(ta), with the latter serving as a measure of directional persistence; cos(ta) will reach its maximum value of 1 when the animal continues to move in the same direction as the previous step and will take on its minimum value of -1 when the animal turns around and moves in the exact opposite direction as the previous step (Prokopenko et al. 2017). Before fitting models to the data, we created plots of log(sl) and cos(ta) versus distance from road for Highway 3 and the Tłı̨chǫ ASR during both before and during construction periods (Figure C-8).

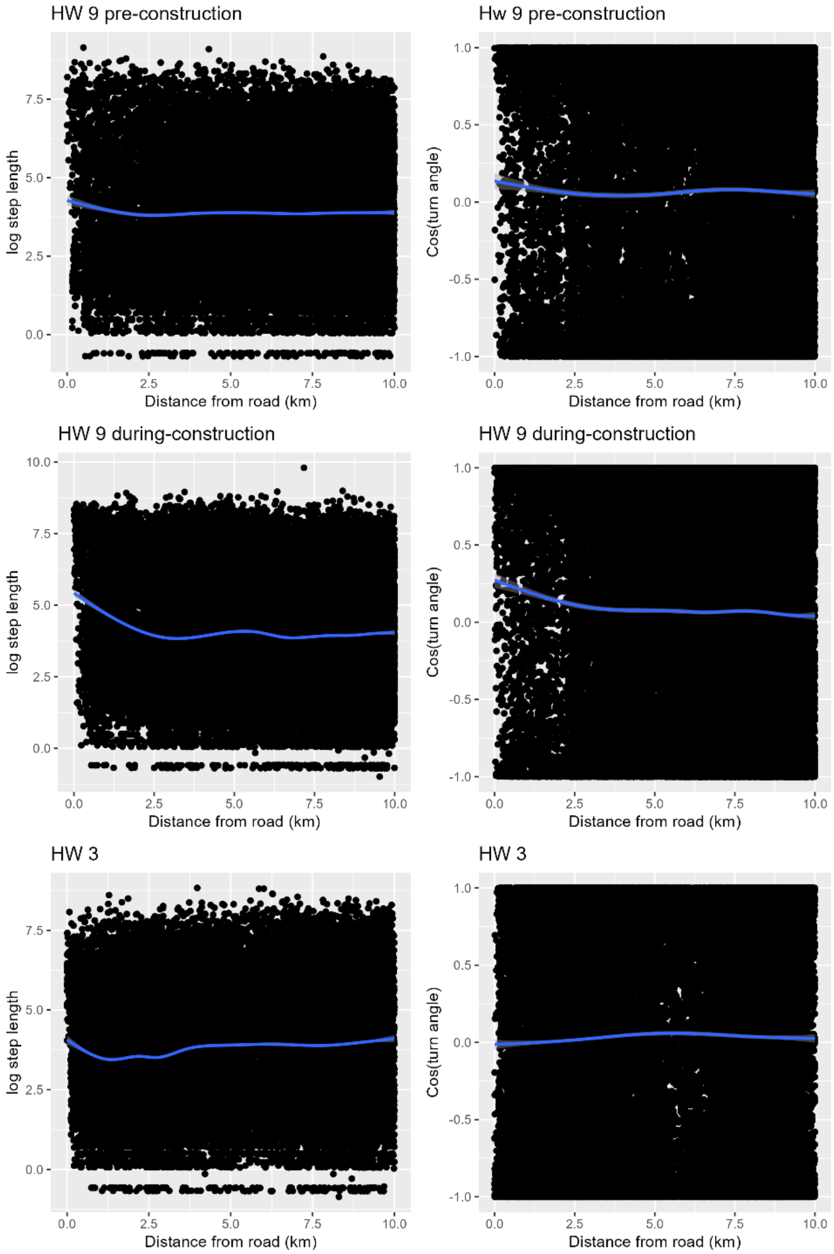

Figure C-8. Observations of log(step length) (left column) and cos(turn angle) (right column) as a function of distance from the Tłı̨chǫ ASR [HW 9] (km) during the pre-construction (first row) and construction (second row) phases of the study and from Highway 3 [HW3] (third row). The blue line is a smooth through the data to help with visualizing trends.

Behaviour of boreal caribou in proximity to roads may also depend on the types of habitat adjacent to the road, and their selection or avoidance of them. To account for caribou habitat preferences, we used a 30-m resolution raster of the relatively likelihood of boreal caribou habitat selection predicted from an all-year resource selection function (RSF) model (DeMars et al. 2020). Predicted RSF values were binned into 10 categories with 1 representing areas most likely to be avoided, and 10 represented areas most likely to be selected. The RSF model included land cover types, binned by upland versus lowland and further broken down into different age categories (years post-wildfire) by decade. The RSF model also included covariates for proximity to human disturbances including roads, settlements, and other polygonal disturbances, and a covariate for the density of linear features.

Piecewise Regression Models

To estimate the zone of influence of the Highway 3 and of the Tłı̨chǫ ASR both before and during construction, we fit piecewise regression models using the *segmented* package (Muggeo and Muggeo 2017) in R (R Core Team 2024). These models estimate a single breakpoint that allows the effect of 'distance to road' to change before and after the breakpoint. Although breakpoint estimates can be appealing for management, they can mask effects that occur on a gradient instead of in discrete intervals. We fit separate models to log(step length) and cos(turn angle) as a function of distance to the road, with a single estimated breakpoint that allowed the effect of distance from road to change before and after the breakpoint. We also included log(dt) (log of the time between sequential observations) since longer observation windows should lead to longer and less directed movements. Further, we included predicted values (at the start of the movement step) from the fitted RSF from DeMars et al. (2020) to control for other environmental factors known to influence caribou movements. We inspected residual plots to evaluate the assumptions of the model (e.g., homogeneity of variance, normally distributed errors) and plotted estimated mean values from the model as a function of distance from road (Figure C-8).

Results

Estimated breakpoints for distance to road in the log(sl) models were 1.425 km (SE = 0.218) (Tłı̨chǫ ASR during pre-construction), 2.494 km (SE = 0.102) (Tłı̨chǫ ASR during construction), and 0.882 km (SE =0.103) (Highway 3), with higher mean log(sl) values occurring when caribou were close to the road (Figure C-8). Yet, there was considerable variability in the log(sl) values (Figure C-8), with the models explaining less than 2% of this variation (R^2 ranged from 0.002 to 0.016). As expected, the coefficients for log(dt) were positive, indicating step lengths were longer, on average, when the observation window was longer. Coefficients for the habitat covariate were negative, indicating step-lengths were smaller, on average, when individuals were in favorable habitat.

Estimated breakpoints for distance to road in the cos(ta) models were 1.445 km (SE = 0.3) (Tłı̨chǫ ASR during pre-construction), 2.464 km (SE = 0.326) (Tłı̨chǫ ASR during construction), and 5.28 km (SE = 0.449) (Highway 3), with caribou exhibiting more directed movements when close to the Tłı̨chǫ ASR and less directed movements when close to Highway 3 (Figure C-8). There was considerable variability in the cos(ta) values (Figure C-8), with the models explaining less than 1% of this variation (R^2 ranged from 0.0005 to 0.002).

Residuals from the models were not normally distributed, and the residuals from the log(sl) models exhibited a trend when plotted against fitted values, suggesting that a more flexible model may better fit the data. This led us to fit generalized additive models discussed in the next section. We also note that we assumed all observations were independent despite having repeated observations on multiple individuals, with observations also likely exhibiting temporal autocorrelation. Thus, the p-values are likely smaller and confidence intervals narrower than they should be if this correlation were properly addressed (e.g., through the inclusion of random effects).

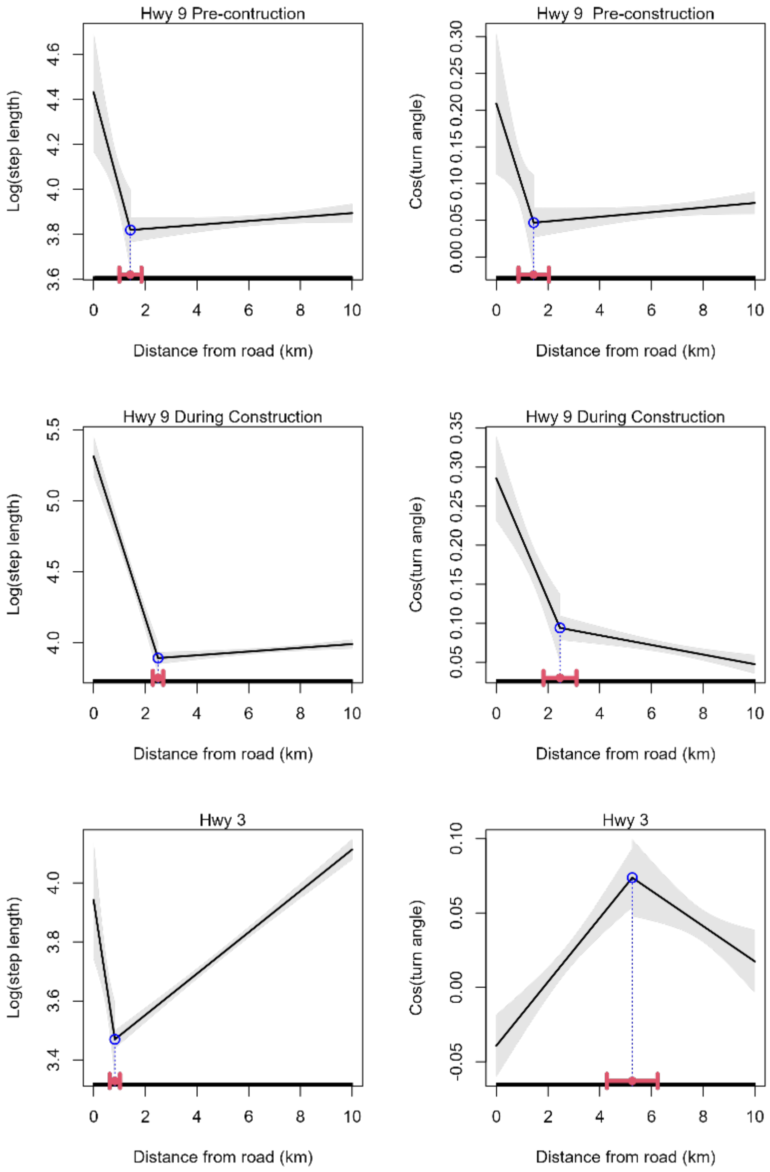

Figure C-9. Estimated mean log(sl) (left column) and cos(ta) (right column) as a function of distance from road for the Tłı̨chǫ ASR during the pre (top row) and during (middle row) construction phases of the study and for Highway 3 (bottom row) from fitted piecewise linear regression models. The estimated breakpoints with associated 95% confidence intervals are shown in red along the x axis. When forming predictions, log(dt) and the habitat covariate were set to their mean values.

Generalized Additive Models

We fit generalized additive models (GAMs) to estimate non-linear (smooth) effects of distance from road on log(sl) and cos(ta) using the gam() function in the *mgcv* package (Wood 2017). We fit the models to the same data partitions as used to fit the piecewise regression models and similarly included log(dt) and the habitat covariate. We used the gam.check() function to evaluate model assumptions and plotted estimated mean values (Figure C-10).

Results

Estimated trends in log(sl) and cos(ta) were similar to those from the piecewise regression models (compare Figures C-9 and C-10), but the GAMs allowed for additional flexibility in the modeled response with respect to distance from road. This improved the residual plots for the log(sl) models. R^2 values remained low, however, and again we note we assumed all observations were statistically independent, so p-values are likely smaller and confidence intervals narrower than they should be if the correlation were properly addressed.

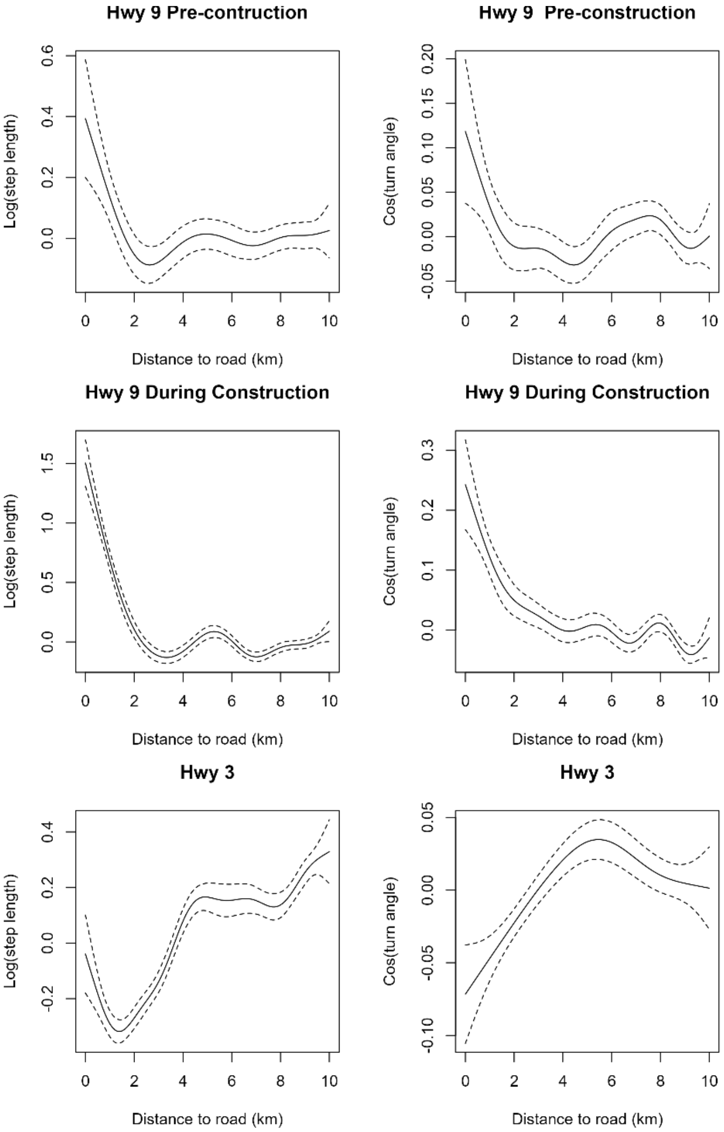

Figure C-10. Estimates of the effect of distance from road on mean log(sl) (left column) and cos(ta) (right column) for the Tłı̨chǫ ASR during the pre (top row) and during (middle row) construction phases of the study and for Highway 3 (bottom row) from fitted generalized additive models. Dotted lines represent 95% confidence intervals.

Summary

We detected a behavioural change in movement characteristics as animals approached the Tłı̨chǫ ASR. Specifically, we observed longer step lengths and more directed movements (cos(ta) closer to 1) when animals were within approximately 2 km of the highway. We also detected a change in movement behaviors when individuals approached Highway 3, but the relationships between log(sl), cos(ta) and distance to road was more complicated (Figure C-10) and challenging to interpret. It is also important to recognize that step lengths and turn angles were highly variable, with the effect of distance to road explaining relatively little of this variation.

Integrated Step-Selection Analyses

Data Filtering and Pre-processing

Similar to the piecewise regression and generalized additive models, this analysis only included steps where the time between successive locations was 1 hour +/- 10 minutes. This excluded any steps that started outside of the 10 km geofences for Highway 3 and the Tłı̨chǫ ASR because locations were collected every four hours outside of these areas, and it also excluded any steps that were two or more hours apart due to missing GPS transmissions.

Integrated Step-selection Model

We conducted integrated step-selection analyses (Avgar et al. 2016; Fieberg et al. 2021) to quantify how caribou select habitat and change their movements when near Highway 3 and the Tłı̨chǫ ASR. Integrated step-selection analyses assume that animal space use is captured by the product of two kernels, a selection-free movement kernel, $\phi(.)$, that quantifies how the animal would move in the absence of habitat selection and a movement-free selection kernel, $w(.)$, representing habitat preferences (Fieberg et al. 2021):

$$\mathrm{u}(s, t+\Delta t) \mid \mathrm{u}(s',t), \omega \sim \phi(s,s', \omega, \mathrm{x}(s', t);\gamma)w(\mathrm{x}(s,t+\Delta t); \beta)$$

where $\sim$ indicates the left and right-hand-sides are proportional to one another, $\mathrm{u}(s, t+\Delta t) \mid \mathrm{u}(s',t), \omega$ represents the conditional probability of an animal being present at location s at time $t+\Delta t$, given that it was at location s' at time t and arrived at this location via bearing ω, $\mathrm{x}(s', t)$ and $\mathrm{x}(s, t+\Delta t)$ are habitat covariates measured at the start and end of the movement step, respectively, and β and γ are sets of parameters that quantify habitat selection and movement capabilities, respectively.

We modeled $w(.)$ as a log-linear function of distance to road at the end of the movement step, using random effects to allow each individual to have its own selection coefficient (Muff et al. 2020). We also included predicted habitat values (at the end of the movement step) from a fitted resource selection function from DeMars et al. (2020) to control for other environmental factors known to influence caribou movements.

To specify the selection-free movement kernel, we assumed step lengths followed a gamma distribution and turn angles followed a von Mises distribution. We allowed the distribution of step lengths and turn angles to also depend on distance from road at the start of the movement step by including interactions between distance from road and step length, log step length, and cos(turn angle) following the approach of Avgar et al. (2016).

We prepared the data for the integrated step-selection analysis using the *amt* package (Signer et al. 2019), which required fitting tentative movement parameters to the empirical step lengths and turn angles and then simulating random steps using these movement parameters. Observed and random steps were then combined into strata and analyzed by fitting a generalized linear mixed effects model to the data using *glmmTMB* (Brooks et al. 2017, package version 1(3)) in R 4.0 (R Core Team 2021) and the "Poisson trick" developed by Muff et al. (2020). Lastly, we used the coefficients associated with step length, log step length, cos(turn angle) and their interaction with distance to road to estimate selection-free movement kernels for a range of distances to road. We used functions in the *mixedSSA* package (Freeman 2024) to visualize the estimated habitat selection parameters and movement kernels.

Results

The estimated step-length distributions were right skewed, with means that were considerably larger than the corresponding medians (Figures C-11 and C-12). Although estimated mean step lengths were slightly larger when caribou were near the Tłı̨chǫ ASR during the pre-construction phase of the study (Figure C-12), this effect was small and estimated median step lengths were similar for all quantiles of distance from road. Similarly, distance from road had very little effect on the distribution of turn angles during the pre-construction phase of the study (Figure C-11). The effect of distance from road on step lengths was statistically significant (p-values for the interaction terms between distance from road and sl and log(sl) were both < 0.001) but the effect on turn angles was not (p-value = 0.632).

The effect of distance from road was more pronounced during the construction phase of the study, with higher mean and median step lengths estimated when caribou were close to the Tłı̨chǫ ASR (Figure C-12). The estimated distribution of turn angles also became more concentrated on 0, indicating more directed movements when caribou were close to the road (Figure C-11). The effects of distance from road on step lengths and turn angles were statistically significant (p-values for all interaction terms were < 0.001).

In contrast to the results for the Tłı̨chǫ ASR, estimated mean and median step length decreased and turn angles were estimated to be less concentrated on values near 0 as caribou approached Highway 3 (Figures C-11 and C-12). Again, these effects were statistically significant (p-values for the interaction terms with sl and log(sl) were < 0.001, and the p-value for the interaction term with cos(ta) was 0.0023). These contrasting results likely reflect differences in how caribou view Highway 3 and the Tłı̨chǫ ASR. Caribou were much more likely to cross the Tłı̨chǫ ASR than Highway 3. When approaching the Tłı̨chǫ ASR, they often crossed quickly, resulting in longer and more directed steps.

By contrast, they rarely crossed Highway 3 and often changed their direction and moved less in its vicinity.

Lastly, we estimated positive selection coefficients associated with the habitat layer and with the distance from road covariate for both construction phases associated with the Tłı̨chǫ ASR and for Highway 3 (Table C-3). These results suggest that caribou selected for areas associated with high habitat suitability values and that were farther from the road.

Table C-3. Estimated coefficients (SE) for distance to road and habitat suitability covariates associated with a “typical individual” (i.e., one with coefficients set to their mean values in the population; Fieberg et al. (2009)).

	Tłı̨chǫ ASR pre-construction	**Tłı̨chǫ ASR during construction**	**Highway 3**
Distance from road	0.112 (0.018)	0.108 (0.016)	0.100 (0.032)
Habitat covariate	0.060 (0.007)	0.065 (0.006)	0.070 (0.006)

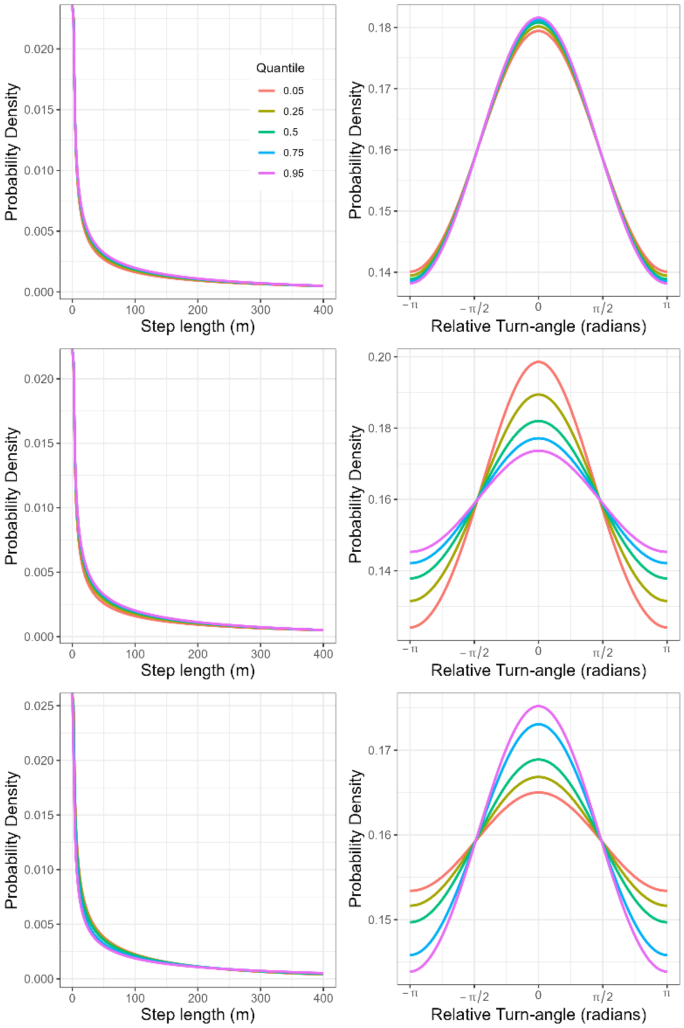

Figure C-11. Estimated distributions of step length (left column) and turn angle (right column) for different quantiles of distance from road during the pre (top row) and during (middle row) construction phases of the Tłı̨chǫ ASR and for Highway 3 (bottom row) from fitted integrated step-selection models. The x-axis was truncated to 400 m for the step-length distribution plots to help with visualizing differences as a function of distance to road. Distributions are shown for a "typical individual" (i.e., one with coefficients set to their mean values in the population; Fieberg et al. (2009)).

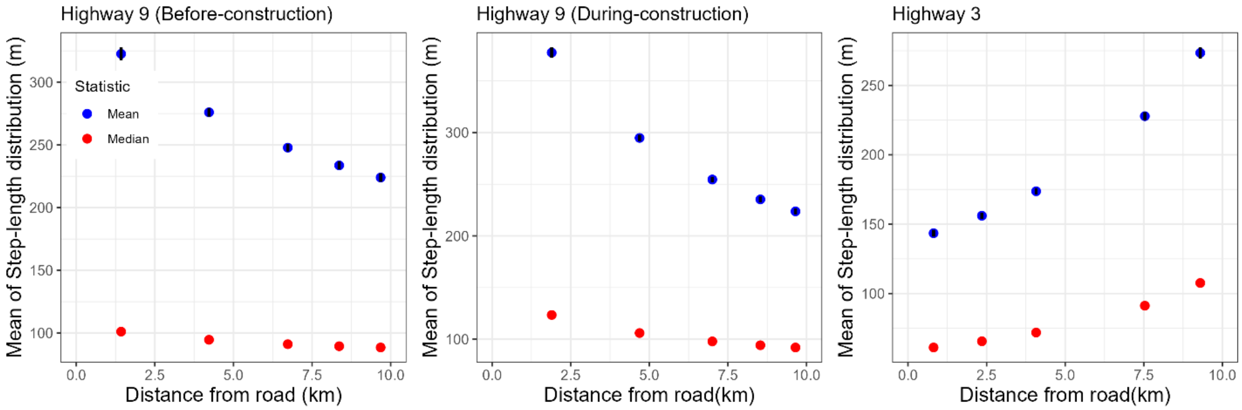

Figure C-12. Estimated mean and median step lengths for different quantiles of distance from road (5%, 25% 50% 75% and 95%) for a "typical individual" (i.e., one with coefficients set to their mean values in the population; Fieberg et al. (2009)) during the pre (left panel) and (middle panel) construction phases of the Tłı̨chǫ ASR [Highway 9] and for Highway 3 (right panel) from fitted integrated step-selection models.

Summary

Similar to the piecewise regression and generalized additive models, we found that caribou moved faster and more directed when close to the Tłı̨chǫ ASR during the construction phase of the study. By contrast, caribou moved less, and their movements were less directed as they approached Highway 3.

The integrated step-selection analysis offers several advantages relative to the regression models of the previous section in that they use more appropriate statistical distributions (gamma distribution for step lengths and von Mises distribution for turn angles rather than normal distributions for log(sl) and co(ta)). Furthermore, we incorporated random effects to account for repeated measures on the same individuals. We still had to assume that the steps were independent, conditional on these random effects. This assumption would be violated if step lengths or turn angles exhibit within-individual autocorrelation.

Effect of Road Encounters on Caribou Movement Behaviours

Animal responses to linear features like roads can be more complex than changes in step length distance and turn angles and can include changes in behaviours like 'patrolling' or tracing alongside the road, deflecting away from the road, or continuing to move normally near the road. The barrier behaviour analysis (BaBA; Xu et al. (2021)) provides a useful tool for detecting and categorizing these behavioural changes. In this framework, animal movements that occur within a specified distance from the road are considered encounter events and are classified into one of six barrier behaviour types across three movement types: normal movements, altered movements, and trapped movements. Normal movement includes average movement, when the barrier does not obviously influence animals' movements, and quick cross, when an animal quickly crosses the barrier after it is encountered. We note that these 'normal' movements may be affected by the linear feature in other ways that are not considered here; for example, movement speed (i.e., crossing faster to avoid being close to the road). Altered movements include bounce, when the animal quickly moves away from the barrier; back-and-forth, when the animal stays close to the barrier by going back and forth; and trace, where the animal stays close to the barrier and moves alongside it. Back-and-forth and trace movements may ultimately lead to a crossing event, but because there was a delay in crossing the road after encountering the barrier, it is considered an altered movement. Trapped movements are when animals' movements are constantly near a barrier, suggesting an animal is constrained by the barrier (Figure C-13).

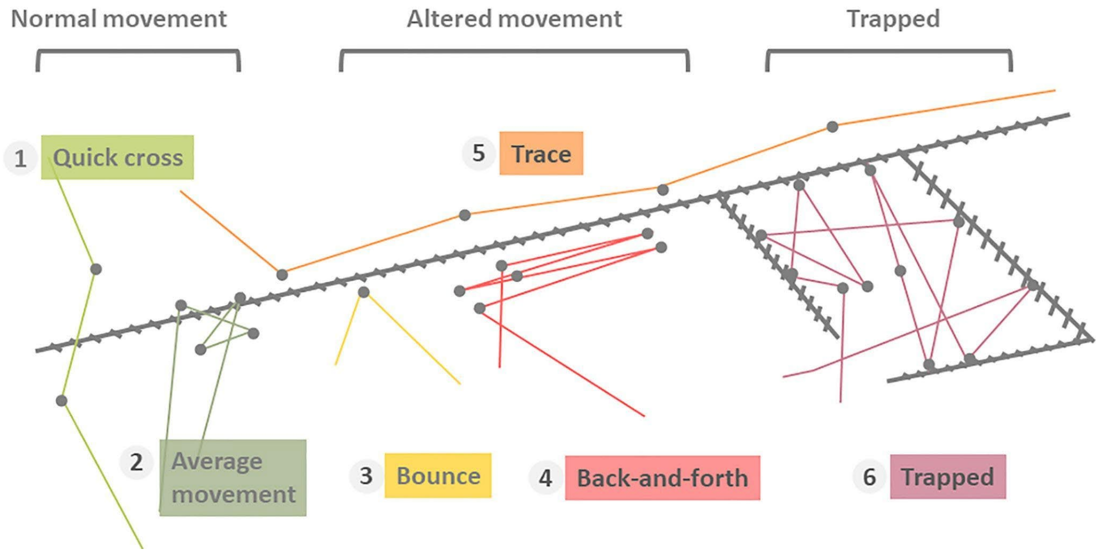

Figure C-13. Schematic diagram of the different behaviour types identified using the barrier behaviour analysis (BaBA) (from Xu et al. 2020).

Using the *BaBA* R package (Xu and Herrmann 2024), for a given barrier and a dataset of animal locations (consisting of regular location fixes over time), any set of consecutive animal locations that fall within a user-defined buffer radius of this barrier are considered "encounter events". Each "encounter event" is then classified as a particular behaviour based on its unique quantitative metrics: duration, straightness, and number of intersections with the barrier (Xu et al 2021). These metrics are classified using a set of user defined parameters and arguments. These include: the barrier buffer size ("d"), the minimum time duration for an encounter to be considered a "trapped" behaviour ("p_time"), the minimum and maximum time intervals for the classification of behaviours ("tmin" and "tmax", where tmax – tmin = duration of a given encounter), the length of time to calculate the average straightness of an encounter within a moving window ("w"), the maximum time duration that GPS locations can emerge outside the buffer for within a given encounter event ("tolerance"), the maximum number of intersections or crossings that occur with the barrier ("max_cross", specifically used for trace and back-and-forth behaviours), the number of standard deviations that define "normal" straightness values for movement ("sd_multiplier"), and whether to include locations within the barrier buffer when determining the average straightness of movement ("exclude_buffer", useful for controlling barrier effects and when there is a large enough sample size of locations available outside the buffer). The decision of values to use for these parameters and arguments is primarily up to the user but a set of "starting" parameters can be used, with "optimal" values being chosen with a sensitivity analysis, where a parameter of interest is varied while holding other values constant and comparing the proportional impact on classified behaviours.

The buffer defines the distance from the road where individual caribou movements will be considered an “encounter” with the road and classified into one of six behavior types. Prior to classification, BaBA sorts encounter events into three categories, based on the duration of the encounter compared to the “tmin” parameter: short (duration < tmin), median (tmin < duration < tmax), or prolonged (duration > tmax). For short events, BaBA extends the encounter event to include one GPS location before and one after the encounter event. For median events, BaBA calculates the movement segment straightness ($\overline{\mathbf{str}_{\boldsymbol{iw}}}$) and standard deviation ($\boldsymbol{\sigma}_{iw}$) of each event and compares it to average movement straightness, using a moving window approach from $\frac{w}{2}$ days before until $\frac{w}{2}$ days after the same event. One standard deviation is used to determine if the straightness of the encounter event is different from the associated average movement straightness. Behaviours are then classified as follows:

- *Quick cross*: a short (duration < tmin) event where the movement trajectory intersects the barrier.
- *Bounce*: a short (duration < tmin) event with no intersection with any barrier, i.e., the animal entered the buffer area for a short time and quickly moved away.
- *Average movement*: median duration event, and straightness within 1 SD of average movement straightness ($\mathbf{str}_\mathbf{i}$ is within $\overline{\mathbf{str}_{\boldsymbol{iw}}} \pm \boldsymbol{\sigma}_{iw}$).
- *Back-and-forth*: median duration event, and the movement trajectory is more sinuous than normal ($\mathbf{str}_\mathbf{i} < \overline{\mathbf{str}_{\boldsymbol{iw}}} - \boldsymbol{\sigma}_{iw}$).
- *Trace*: median duration event, and the movement trajectory is less sinuous than normal ($\mathbf{str}_\mathbf{i} > \overline{\mathbf{str}} + \boldsymbol{\sigma}$).
- *Trapped*: when an encounter remains in the buffer for a duration > tmax.
- *Unknown*: classification used under specific criteria due to insufficient data or to account for data resolution (e.g., a short duration event that cannot be extended because it is the beginning or end of the GPS trajectory; a median duration event that cannot be extended to calculate the average straightness for the same reason; or the number of intersections exceed max_cross which is used to account for curvy barriers and coarse GPS resolution; see Xu et al. (2021), supporting information).

We used the BaBA function to classify boreal caribou encounters with the Tłı̨chǫ ASR and with Highway 3 into these six distinct behaviour types. We then compared the frequency of behaviours of caribou in response to encountering the Tłı̨chǫ ASR before construction, the Tłı̨chǫ ASR during construction, and Highway 3. The “before construction” phase of the Tłı̨chǫ ASR included caribou data from March 15, 2017, to September 2, 2019, and the construction phase included caribou data from September 3, 2019, to November 30, 2021.

For this analysis, the boreal caribou GPS collar data was filtered to locations within the 10-km geofence around each road, within which collars were programmed to record locations at 1-hour intervals (instead of four-hour intervals outside the geofence). We subset the data to locations rounded to the 1 hr sampling rate. After subsetting the data, time steps larger than the desired sample rate (1 hr) (e.g., due to missing hourly location fixes) were included in an encounter if the missing locations were within the specified tolerance parameter.

Sensitivity Analysis

We started with a sensitivity analysis to determine if there was sensitivity in the BaBA function to the various parameters described above, and if so, the "optimal" values to use.

The primary parameter of interest was the buffer size ("d" parameter), as the choice of this value influences which movement data will be considered as an encounter and classified into a behaviour type and can greatly impact the behaviour results (Xu et al. 2021). A range of buffer sizes 500-8,000 m (in 500 m intervals) and 100 to 2,000 m (by 100 m intervals) were evaluated for each road category (Tłı̨chǫ ASR pre-construction, Tłı̨chǫ ASR during construction, Highway 3). We set the largest buffer distance at 8,000 m because our dataset of one-hour fixes was only available within 10 km of either road. With each buffer distance, a set of starting parameters were used similar to Xu et al. (2021), with: p_time = 36 hours, b_time = 4 hours, w = 7 days, max_cross = 4, sd_multiplier = 1, exclude_buffer = FALSE, and tolerance = 0. Barplots were used to examine differences in the frequency and proportion of different behaviours for each unique buffer size and road category.

We did not observe a single buffer distance that created a distinct change in behaviour types, although increasing the buffer distance allowed for more locations to be classified as encounters and resulted in more 'average' behaviors farther from the road. Therefore, we selected buffer distances of 500 m, 1,000 m and 1,500 m and tested the sensitivity of the other parameters using each of these buffer distances, keeping values of the parameters not being tested constant at their starting values. We tested the following range of values for other parameters (p_time: 36 and 18 hours; w: 7, 14, and 3.5 days; max_cross: 0, 2, and 4; sd_multiplier: 1 and 0.5; tolerance: 0, 3, and 5 hours; exclude buffer: TRUE and FALSE). Following Xu et al. (2021) we did not test the parameter b_time but kept the minimum time threshold at four hours.

Overall Behavior Analysis

After determining the "optimal" values to use for the BaBA with the sensitivity analysis, we re-examined the role of buffer distance on behaviours by creating new plots using the optimal parameter values and a range of buffer widths. We did not observe obvious breakpoints in behaviour types across buffer distances with the updated parameters, so we selected buffer distances of 500 m, 1,000 m, and 1,500 m to compare the frequency and proportion of behaviours among the three road categories (Tłı̨chǫ ASR pre-construction, Tłı̨chǫ ASR during construction, and Highway 3).

To compare the frequency of key behaviours (e.g., quick cross and bounce behaviours) between each road category, a Pearson's Chi-squared test was used. A test was run for each buffer (500, 1,000, and 1,500 m) and for each pair of road categories (Tłı̨chǫ ASR before construction to Highway 3, Tłı̨chǫ ASR during construction to Highway 3, and Tłı̨chǫ ASR before construction to Tłı̨chǫ ASR during construction) to compare the observed counts for each behaviour.

We also compared behaviour types using the caribou seasons as in previous analyses (pre-calving (April 2-30), calving (May 1 - July 15), summer (July 16 - September 12), early fall (September 13 - October 20), late fall (October 21 - November 30), and winter (December 1 - April 1) to determine if there were seasonal differences in the frequency and proportion of behaviours for each road category. To determine if there was individual variation that may be driving differences in the frequency and proportion of behaviours observed for each road category, the BaBA was also run on each individual caribou.

Results

Sensitivity Analysis

We did not observe clear breakpoints in the proportion of behaviour types across different buffer distances, although the proportion of quick cross behaviours was highest using a buffer distance of 100 m for all three road categories (Supplementary Material, Figures S-1 to S-4). The buffer distance at which "average" behaviours first occurred differed for each road category and increased as buffer distance increased, up to a "stabilizing" distance that also differed for each road category. To determine how a smaller versus larger buffer might affect behaviour classifications for the three road categories, we decided to use three different buffer distances (500, 1,000, and 1,500 m) to test the sensitivity of the remaining parameters.

For the "p_time" parameter (the minimum time duration for an encounter event to be considered a "trapped" behaviour), the "w" parameter (the moving window size used in calculating average straightness of movement), and the "max_cross" parameter (the maximum number of crosses to be allowed for detecting trace and back-and-forth behaviours), sensitivity results showed no or minor changes to the behaviours detected at the three buffer distances (Supplementary Material, Figures S-5 to S-7). Therefore, the starting parameters were retained as optimal. For the "sd_multiplier" parameter, which is the number of standard deviations that define "normal" straightness values for movement, we compared SD values of 1.0 (starting value) and 0.5, observing differences in behaviour types up to 9% depending on the buffer distance (Supplementary Material, Figure S-8). An SD of 0.5 was chosen to use going forward, as it allows for more "back-and-forth" and "trace" behaviours to be identified. For the "exclude_buffer" parameter, which specifies whether to include locations within the barrier buffer when determining the average straightness of movement and can be useful for controlling barrier effects, we also found differences in behaviour types from setting the parameter as "TRUE" or "FALSE" (Supplementary Material, Figure S-9). Because we observed a larger number of "unknowns" with the exclude_buffer of "TRUE" and because Xu et al. (2021) also used an exclude_buffer of "FALSE", we retained "FALSE" as the optimal choice. For the "tolerance" parameter (the maximum duration to allow points outside of the buffer and between two sets of points that are inside the buffer to be considered a continuous encounter event), we found differences in behaviour types of up to 6% (Supplementary Material, Figure S-10). We chose a tolerance of three hours, as having a few locations leave the buffer during an encounter is logical.

Behaviour Analysis: Comparison of Road Categories

For all subsequent analyses, we used the parameters selected with the sensitivity analysis (p_time of 36 hours, w of 7 days, max_cross of 2, sd_multiplier of 0.5, and tolerance of 3 hours).

Re-running the BaBA for a range of buffer widths (100 to 2,000 m, by 100 m intervals) with the chosen parameters from the sensitivity analysis showed differences in the frequency and proportion of behaviours for each road category (Figures C-14 and C-15).

For Highway 3, the dominant behaviour capturing effects of this highway on caribou was "bounce" behaviour, which decreased in proportion until a buffer distance of around 1,500 m (Figure C-15). For the Tłı̨chǫ ASR, the proportion of "quick cross" behaviours decreased during construction compared to before construction but stabilized at a buffer distance of around 1,500 m during construction (Figure C-15). However, the small variations in the proportion of "quick cross" behaviours at buffer distances of 500-1,500 m also support that there may be multiple scales of road effects on caribou behaviour (Figure C-15). Given this observation, we decided to compare results for the rest of the analysis at three buffer distances: 500 m, 1,000 m, and 1,500 m (Figure C-16).

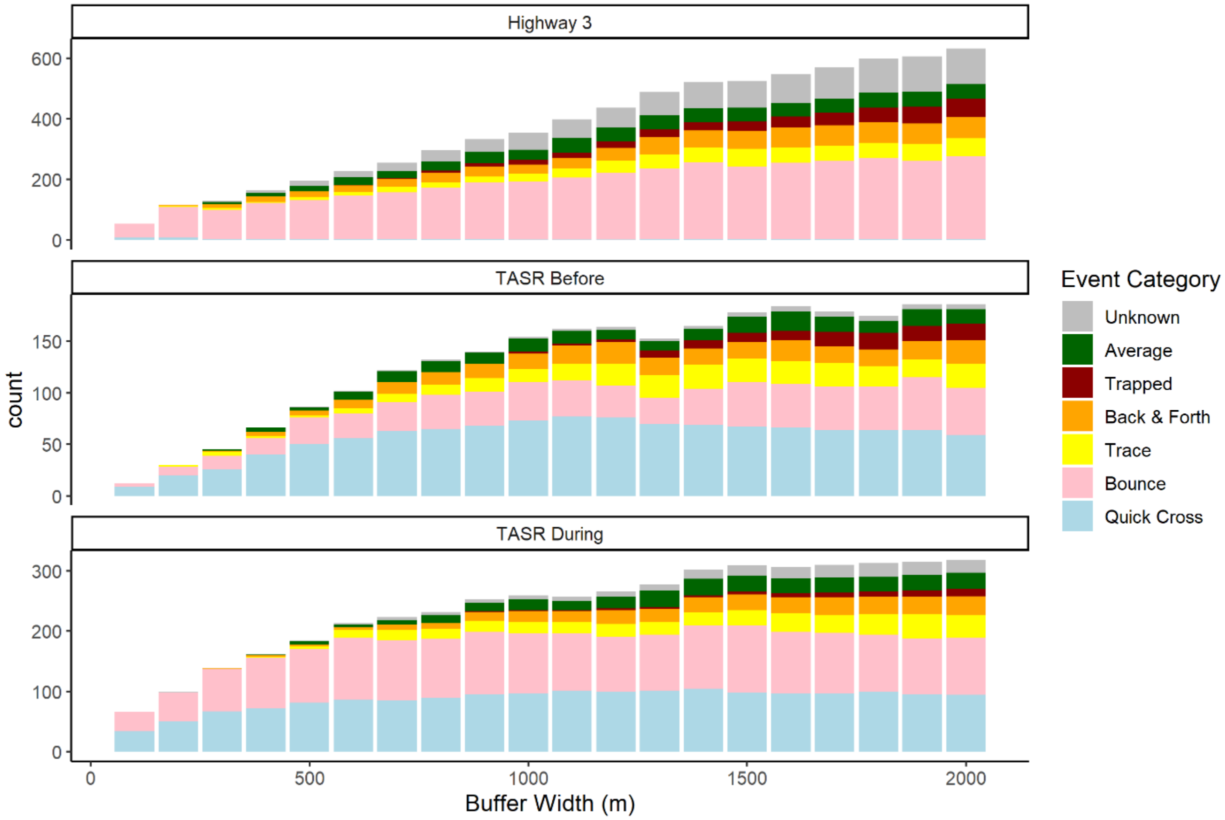

Figure C-14. Barplots of the frequency of various behaviour types for a range of buffer distances (100 to 2,000 m, by 100 m intervals) and the different highway categories of interest (Highway 3, Tłı̨chǫ ASR [TASR] before construction, and TASR during construction). Note: y-axis ranges differ to allow for effective comparison between road categories.

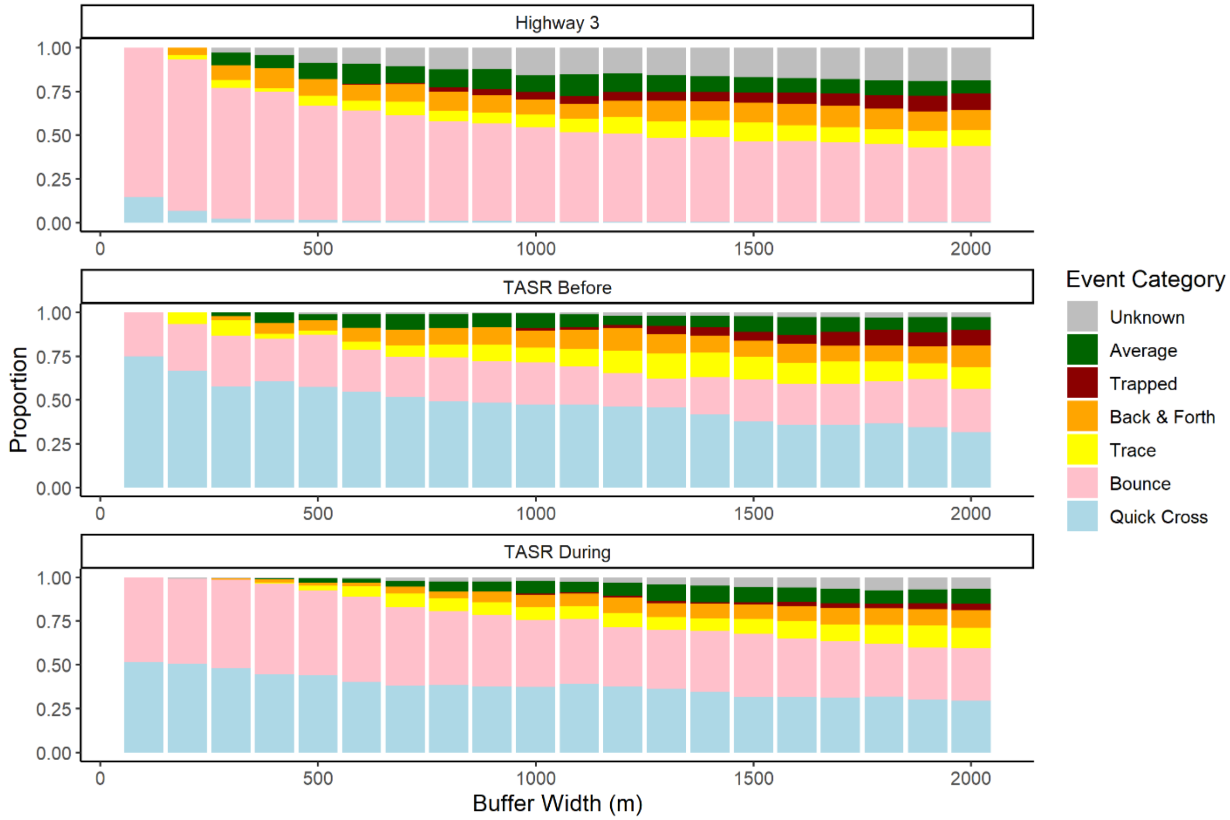

Figure C-15. Barplots of the proportion of various behaviour types for a range of buffer distances (100 to 2,000 m, by 100 m intervals) and the different highway categories of interest (Highway 3, TASR before construction, and TASR during construction).

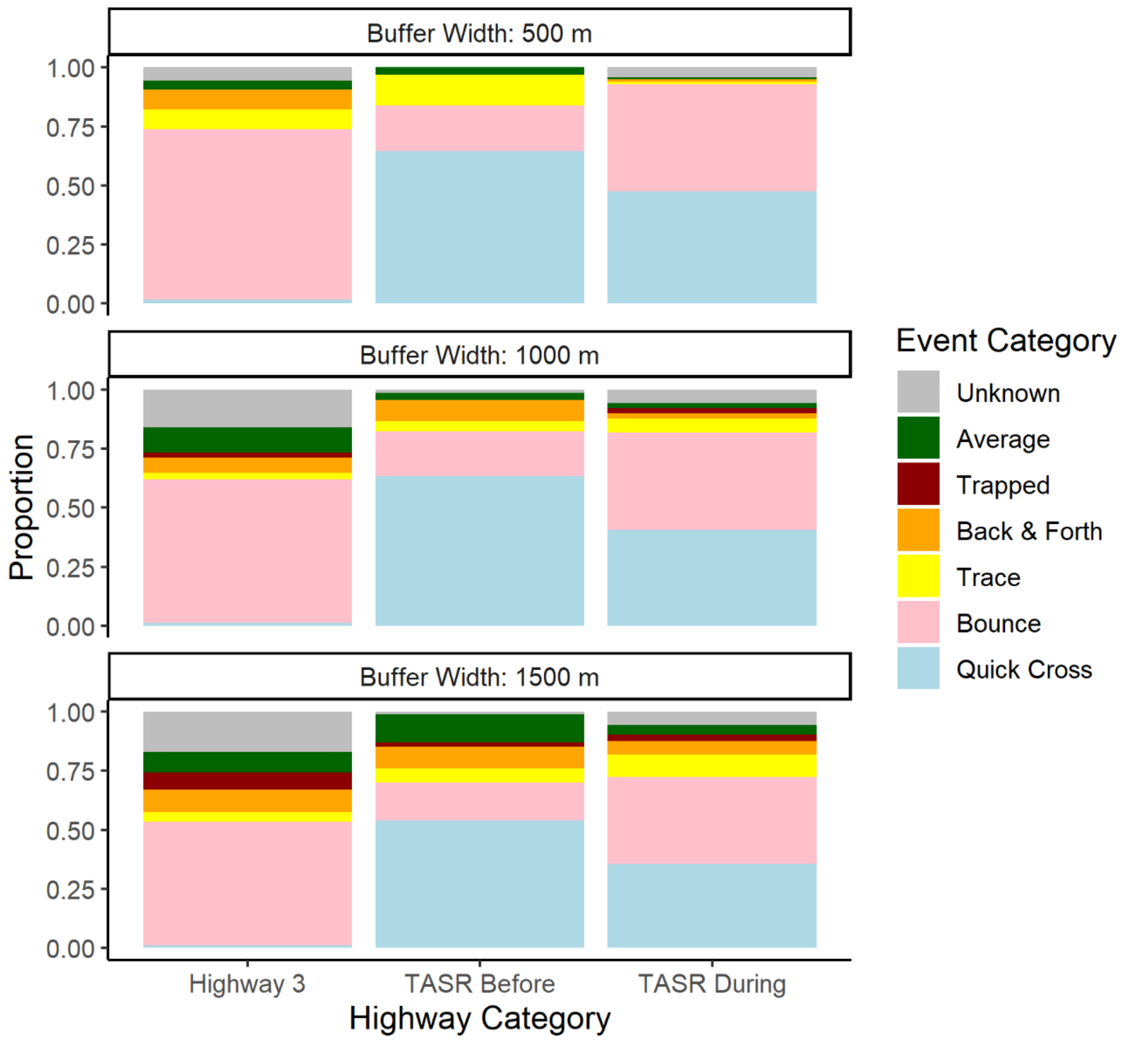

Figure C-16. Barplots of the proportion of various behaviour types for three buffer distances (500, 1,000, and 1,500 m) and comparing the different highway categories of interest (Highway 3, TASR before construction, and TASR during construction).

Using the three buffers of 500, 1,000, and 1,500 m, the three road categories were compared for differences in the proportion and frequency of behaviours found for each. Results showed that across buffer distances, there was largely a difference found in the proportion of quick cross and bounce behaviour categories for the Tłı̨chǫ ASR versus Highway 3 (Figure C-16, Table C-4). For Highway 3, there was a much larger proportion of bounce behaviors detected (~50-70%) and a low proportion of quick cross behaviours (~1-2%), compared to the Tłı̨chǫ ASR before construction (~16-19% bounce, ~50-65% quick cross) (Figure C-16, Table C-4). For the Tłı̨chǫ ASR during construction, a relatively equal proportion of quick cross (~36-47%) and bounce behaviours (~37-45%) was found (Figure C-16, Table C-4). These differences were consistent across the three buffer distances.

Further, the results of our Pearson's Chi-square tests showed that the frequency of quick cross behaviours were significantly different, regardless of buffer size, between the Tłı̨chǫ ASR (both before and during construction) and Highway 3 (Table C-4). The frequency of quick cross behaviours was not statistically different for the Tłı̨chǫ ASR before versus during construction with the 500 m buffer but was with the 1,000 and 1,500 m buffer (Table C-4). For bounce behaviour, results of the Pearson's Chi-square test showed that all road category comparisons (Tłı̨chǫ ASR before construction to Highway 3, Tłı̨chǫ ASR during construction to Highway 3, and Tłı̨chǫ ASR before construction to Tłı̨chǫ ASR during construction) were significantly different, even with different buffer widths (Table C-4).

Table C-4. Results of Pearson's Chi-square tests, applied on each buffer (500, 1,000, and 1,500 m), for the frequency of each behaviour (quick cross versus non-quick cross, bounce versus non-bounce) for each unique pair of road categories (Tłı̨chǫ ASR before construction to Highway 3, Tłı̨chǫ ASR during construction to Highway 3, and Tłı̨chǫ ASR before construction to Tłı̨chǫ ASR during construction). Table shows the p-value, Chi-squared test statistic, and degrees of freedom (df).

Quick cross versus non-quick cross behaviour (500 m buffer)			
Road categories	**df**	**Test statistic**	**P-value**
Tłı̨chǫ ASR before construction and Highway 3	1	65.8	5.0e-16
Tłı̨chǫ ASR during construction and Highway 3	1	56.2	6.6e-14
Tłı̨chǫ ASR before construction and Tłı̨chǫ ASR during construction	1	2.1	0.15
Quick cross versus non-quick cross behaviour (1,000 m buffer)			
Road categories	**df**	**Test statistic**	**P-value**
Tłı̨chǫ ASR before construction and Highway 3	1	105.7	2.2e-16
Tłı̨chǫ ASR during construction and Highway 3	1	66.4	3.7e-16
Tłı̨chǫ ASR before construction and Tłı̨chǫ ASR during construction	1	8.5	0.0036
Quick cross versus non-quick cross behaviour (1,500 m buffer)			
Road categories	**df**	**Test statistic**	**P-value**
Tłı̨chǫ ASR before construction and Highway 3	1	106.9	2.2e-16
Tłı̨chǫ ASR during construction and Highway 3	1	67.5	2.2e-16
Tłı̨chǫ ASR before construction and Tłı̨chǫ ASR during construction	1	8.1	0.0043
Bounce versus non-bounce behaviour (500 m buffer)			
Road categories	**df**	**Test statistic**	**P-value**
Tłı̨chǫ ASR before construction and Highway 3	1	25.6	4.2e-07
Tłı̨chǫ ASR during construction and Highway 3	1	13.8	0.00020
Tłı̨chǫ ASR before construction and Tłı̨chǫ ASR during construction	1	5.6	0.018
Bounce versus non-bounce behaviour (1,000 m buffer)			
Road categories	**df**	**Test statistic**	**P-value**
Tłı̨chǫ ASR before construction and Highway 3	1	30.7	3.0e-08
Tłı̨chǫ ASR during construction and Highway 3	1	10.0	0.0015
Tłı̨chǫ ASR before construction and Tłı̨chǫ ASR during construction	1	9.0	0.0027
Bounce versus non-bounce behaviour (1,500 m buffer)			
Road categories	**df**	**Test statistic**	**P-value**
Tłı̨chǫ ASR before construction and Highway 3	1	33.7	6.4e-09
Tłı̨chǫ ASR during construction and Highway 3	1	8.02	0.0046
Tłı̨chǫ ASR before construction and Tłı̨chǫ ASR during construction	1	12.3	0.00046

Results for the Chi-square tests additionally showed a trend of being more significant (smaller p-value) with a larger buffer size (Table C-4). This is expected, as the frequency of bounce and quick cross behaviours were relatively consistent for each road at buffers of 500, 1,000, and 1,500 m (Figure C-13) but the sample size (number of points within the buffer) increased with buffer size.

These results indicate that Highway 3, which is an established highway with vehicle traffic, had a significantly higher amount of "altered" behaviours, mainly in the form of "bounce" behaviours, with reduced crossings. For the Tłı̨chǫ ASR, the comparison between caribou movements before construction started, and caribou movements during the construction period, shows that constructing the highway impacted caribou behaviour, mainly with a significant increase in altered (bounce) behaviours and a decrease in quick cross behaviours during construction.

Behaviour Analysis: Comparison of Road Categories and Seasons

For Highway 3, comparison of the frequency and proportion of behaviours identified during different seasons (pre-calving, calving, summer, early fall, late fall, winter) showed that for both buffer distances (500 and 1,000 m), there were two seasons where encounters with the road were identified: calving and winter. Calving consisted primarily of quick cross behaviours (but with less than 20 observations (some of which were likely spurious; see *Discussion*) and winter consisted primarily of bounce behaviours (Figures C-17). These results show that that Highway 3 represents a barrier to caribou crossings and that caribou are mainly occurring within 10 km of this road during the winter.

For the Tłı̨chǫ ASR, with a 500 m buffer, caribou demonstrated a high proportion of quick cross behaviours before construction, with behaviours being identified as 100% quick cross in the summer and early fall (n= < 5 crossings in each season) and predominantly quick cross behaviours in other seasons. In comparison, during the construction period, a higher proportion of bounce behaviours were seen for caribou in all seasons except pre-calving (Figure C-17). With this small buffer distance, most late fall and winter movements before construction started were classified as trace, average, and quick cross behaviours with very few bounce events, indicating more normal behaviours close to the road. After construction started, most late fall and winter movements were classified as quick cross or bounce behaviours, with more than 50% of winter encounters classified as bounce.

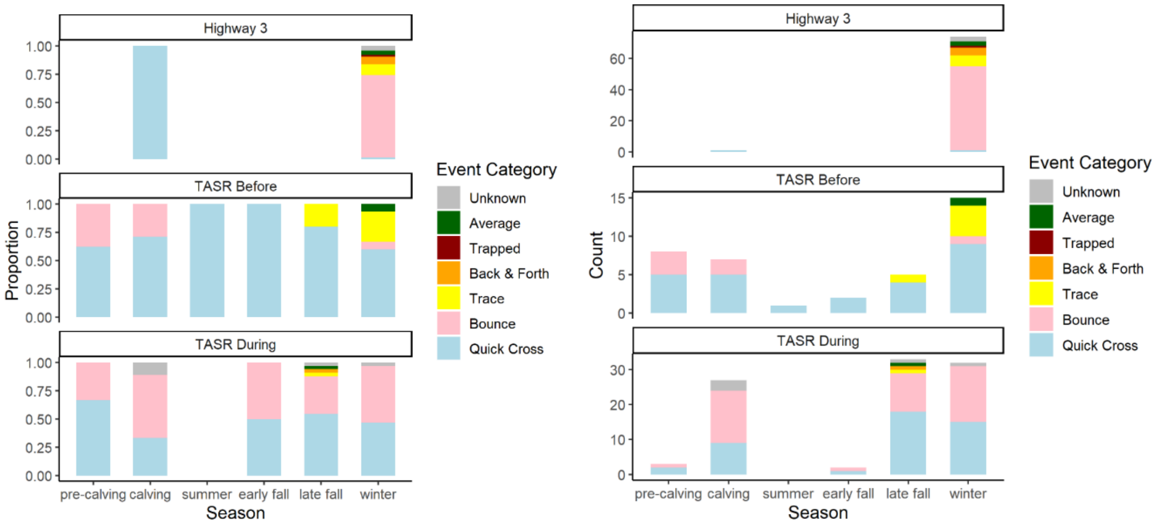

Figure C-17. Barplots of the proportion and frequency of various behaviour types for a buffer distance of 500 m and comparing the different highway categories of interest (Highway 3, Tłı̨chǫ ASR before construction, and Tłı̨chǫ ASR during construction) between seasons: pre-calving (April 2-30), calving (May 1 - July 15), summer (July 16 - September 12), early fall (September 13 - October 20), late fall (October 21 - November 30), and winter (December 1 - April 1). Note: y-axis ranges differ for frequency plots to allow for effective comparison between road categories.

For the Tłı̨chǫ ASR with a 1,000 m buffer, seasonal results somewhat differed, with a higher proportion of trapped, trace, and other (non-bounce and non-quick cross) behaviours detected in the calving season during the construction period compared to the before construction period. The number of caribou encounters with the Tłı̨chǫ ASR differed seasonally for the two time periods of interest. There were few encounters in summer and early fall in either time period (Figure C-18). However, there were more encounters with the Tłı̨chǫ ASR alignment in the pre-calving season before construction started compared to the during construction period, where there were more encounters with the Tłı̨chǫ ASR in the late fall season (Figure C-18). With the 1,000 m buffer distance, overall, a higher proportion of bounce behaviours were seen for the "during construction" phase for all seasons compared to the "before construction" phase, further supporting that construction of the Tłı̨chǫ ASR contributed to altered behaviours for the caribou.

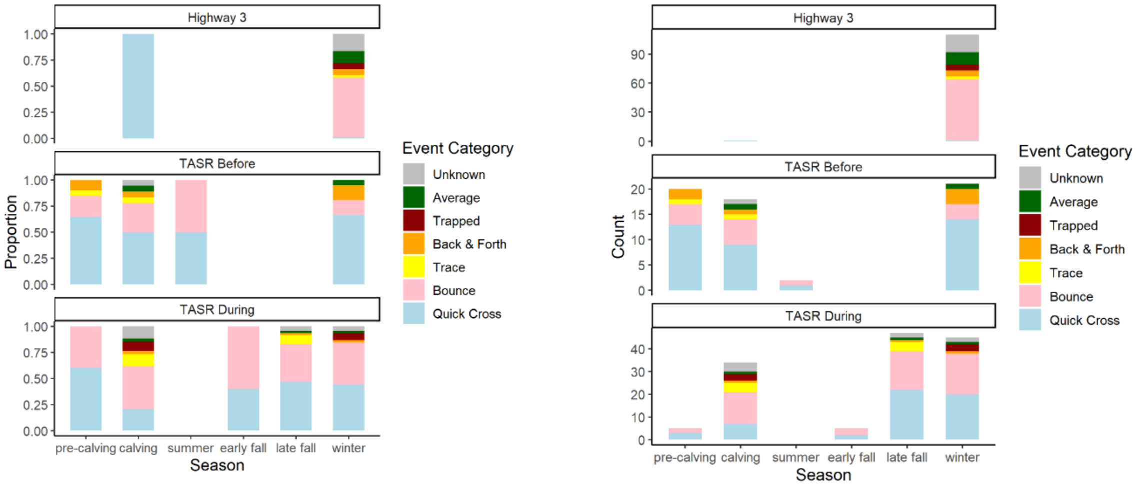

Figure C-18. Barplots of the proportion and frequency of various behaviour types for a buffer distance of 1,000 m and comparing the different highway categories of interest (Highway 3, Tłı̨chǫ ASR before construction, and Tłı̨chǫ ASR during construction) between seasons: pre-calving (April 2-30), calving (May 1 - July 15), summer (July 16 - September 12), early fall (September 13 - October 20), late fall (October 21 - November 30), and winter (December 1 - April 1). Note: y-axis ranges differ for frequency plots to allow for effective comparison between road categories.

<u>Behaviour Analysis: Comparison of Road Categories and Individuals</u>

For individual caribou, results primarily showed for both buffers (500 and 1,000 m), the proportion of behaviours detected (specifically of quick cross versus bounce behaviours) were in support of the results found in the previous sections.

Most individuals encountering Highway 3 had a high proportion of bounce behaviours compared to quick cross behaviours (Supplementary Material, Figures S-11 and S-13). For individuals encountering the Tłı̨chǫ ASR during construction, a higher proportion of bounce behaviours compared to the “before construction” phase was detected (Supplementary Materials, Figures S-11 and S-13). Notably, a couple of individuals (BWCA 19600 and 19602 with Highway 3 and BWCA 19606 with the Tłı̨chǫ ASR during construction) had a much higher number of encounters (>15) compared to other individuals, although the proportions of behaviour for these individuals followed similar patterns to other individuals with fewer encounters (Supplementary Materials, Figures S-12 and S-14). This supports that individual variation is not driving the differences in bounce versus quick cross behaviours found for each road category but instead, that the barrier effects are largely impacting the proportion and frequency of behaviours found.

Summary and Discussion

Application of the BaBA to Boreal Caribou

The BaBA is a useful tool for identifying and classifying animal encounters with a barrier. The different behaviour classes available allow for a variety of impacted behaviours to be identified with respect to a barrier, including “trace” and “back-and-forth” behaviours (infers the animal is moving alongside or towards/away from the barrier, perhaps searching for a preferred crossing spot), “bounce” behaviours (implies the animal has intended to cross but cannot, due to some deterrent, e.g., high vehicle traffic), “quick cross” behaviours (infers the animal has directed, fast movement across the barrier, potentially due to dispersal reasons or wanting to cross quickly to avoid an oncoming obstacle, such as a vehicle), and “average” behaviours (a category to capture “normal” behaviours of the animal.

However, notably when large buffers are defined (e.g., over 2,500 m from the barrier, in our case), an animal moving within this larger buffer in a less sinuous (straighter) way than normal will be identified with the BaBA as demonstrating “trace” behaviour, even if it remains far away from the barrier. According to the BaBA documentation, any encounter event within this buffer that is considered to be “straighter than normal” (with a straightness greater than the average straightness plus the standard deviation of straightness) would be classified as a “trace” behaviour; any encounter event within this buffer that is considered to be “less straight or more tortuous than normal” (with a straightness less than the average straightness minus the standard deviation of straightness) would be classified as “back-and-forth” behaviour; and any encounter event occurring within the middle of this distribution (average straightness +/- the standard deviation of straightness) would be classified as “average” behaviour. Because of this method of classification, for large buffers where the animal may not be anywhere near the barrier, movements may still be classified as “back-and-forth” or “trace” behaviour (as barrier encounters), even when the animal is not responding specifically to the barrier but potentially to a different driver in their environment (e.g., resources). This supports the conclusion by Xu et al. (2021) that the choice of distance used for the barrier buffer is a) influential in the behaviours identified with the method and b) should be chosen based on the spatial scale of interaction expected by the biologist. We largely chose to examine buffers <2,000 m in our main analysis due to this spatial scale being the maximum at which encounters with the barriers were expected to occur for our caribou (who were also sampled at relatively fine intervals of hourly positions).

Interpreting Behaviour Types Identified with the BaBA

Xu et al. (2021) used the quick cross behaviours identified with the BaBA to detect the scale of the impact of a given barrier, assuming wildlife were exhibiting directed dispersal movements (i.e., motivated to get from region A to region B, regardless of barrier presence in between). In our study, the proportion of quick-cross behaviour was highest using a 100 m buffer distance for all three road categories, with the proportion of this behaviour leveling off around 300 m for Highway 3 and around 1,500 m for the Tłı̨chǫ ASR. Notably, at the 100 m buffer distance for Highway 3 and for the Tłı̨chǫ ASR before construction and at the 100-300 m buffer distance for the Tłı̨chǫ ASR during construction, the only behaviours identified were either quick cross or bounce, indicating that they never spent more than four hours (the “b_time” parameter) within the buffer at these distances. With larger buffer distances, a larger variety of behaviours were identified, with "average" behaviour providing the most insight into the distances at which caribou began to demonstrate non-quick cross or bounce behaviours in response to the road.

Quick cross behaviours were observed at all observed buffer distances (up to 8,000 m) for the Tłı̨chǫ ASR, both before and during construction. This suggests that in some cases, caribou are motivated to get from region A to region B, regardless of the presence of the Tłı̨chǫ ASR. Notably, this does not suggest that the road is not providing a disturbance that is altering animal movement; animals may also demonstrate "quick cross" behaviours where they rush across a road in a short time period if they are at risk or disturbed either on or near a road. However, at the larger buffer distances (e.g., 2,500-8,000 m), detection of this "quick cross" behaviour demonstrates that the animal began a "short" encounter (defined here as within four hours, our "b_time" parameter) greater than the buffer distance (e.g., 8,000 m) and quite far away from the road, supporting that the behaviour is likely due to directed dispersal, not disturbance.

Data Resolution and Spurious Crossing Events

Given that the BaBA is largely sensitive to chosen buffer sizes and other parameters that are in turn largely dependent on the resolution of the data, it is likely that some of the identified encounters or crossing events in our study were actually an artifact of the spatial and/or temporal resolution of the data. As example, encounters classified as "quick cross" behaviours may in some instances be mis-classified "bounce" behaviours due to the data resolution making it appear that a location is on the other side of the road (crossed) when it did not (e.g., see Figure C-4). A future option is to remove these road 'crossings' that are a distance smaller than the accuracy of the GPS collar data, as was done for the road crossing rates analysis.

However, user-choice of the buffer distance likely primarily influenced categorized behaviours, not data resolution. For example, the detection of "trapped" behaviours in our analysis at larger buffer sizes (around 1,500+ m) is likely caribou simply moving back and forth within the buffer; an increase in "trapped" behaviours with a greater distance from the road is more likely due to resource selection, e.g., foraging, within the defined buffer distance of the road. Similarly, "trace" behaviours, as discussed above may be misclassified as encounters for large buffer sizes, further supporting that users should use a buffer distance within a reasonable disturbance radius of the road of interest.

Influence of Habitat on Encounter Classifications

When using buffer distances greater than 800 m, we observed caribou to have proportionally more "average" movements within proximity of Highway 3 compared to being in proximity of the Tłı̨chǫ ASR during construction. This is likely due to habitat configuration, with higher-quality winter habitat occurring on both sides of Highway 3 and occurring closer to Highway 3 than to the Tłı̨chǫ ASR. However, we also observed a dominance of "bounce" behaviours in close (< 500 m) proximity to Highway 3, supporting that caribou may experience trade-offs in accessing quality winter habitat while maintaining a preferred and further distance from the road.

Road Impacts on Caribou Behaviour

Our results show that Highway 3 resulted in a high proportion of "altered" movements in the form of bounce behaviours, with caribou movements being deflected off of this barrier. Further, our results show that the construction period of the Tłı̨chǫ ASR resulted in a significantly higher frequency of altered movements and bounce behaviour compared to before construction, supporting that construction of this all-season road resulted in changes to caribou behaviour. These results were consistent regardless of buffer size, supporting that although buffer size can be an important parameter to specify with the BaBA, buffer sizes 500-1,500 showed the same results with respect to altered behaviour.

Our seasonal analysis highlights that during construction, caribou had most encounters with the Tłı̨chǫ ASR in the calving, late fall, and winter seasons. The higher proportion of altered and bounce behaviours observed in the calving season during construction of the Tłı̨chǫ ASR raises concerns that the established Tłı̨chǫ ASR may have negative impacts on this ecologically important season, with caribou potentially being deterred from accessing preferred calving sites by changing their movements in response to the Tłı̨chǫ ASR during the pre-calving and calving seasons.

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Supplementary Material. Sensitivity Analysis for Barrier Behaviour Analysis (BaBA)

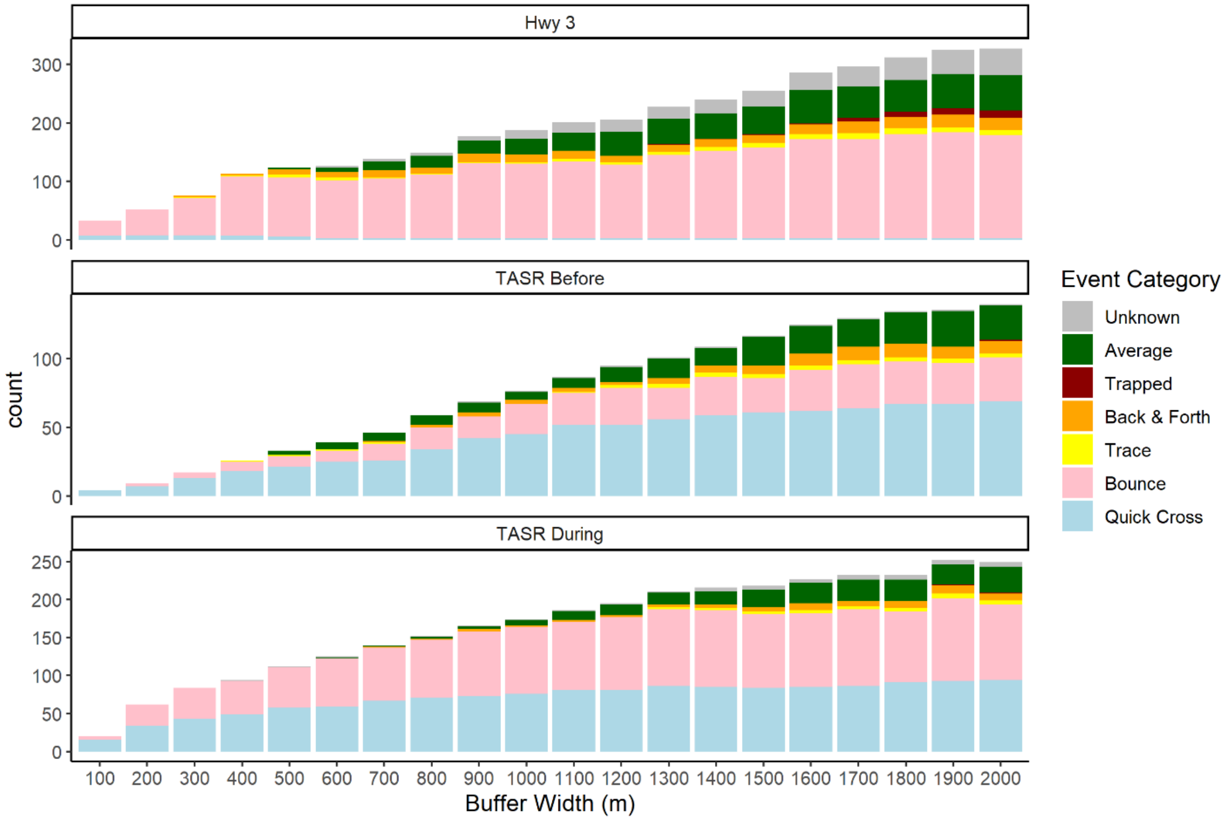

Figure S-1. Barplots of the proportion of various behaviour types for a range of buffer distances (100 to 2,000 m, by 100 m intervals) and for the different highway categories of interest (Highway 3, Tłı̨chǫ ASR before construction, and Tłı̨chǫ ASR during construction), using the starting parameters: p_time = 36 hours, b_time = 4 hours, w = 7 days, max_cross = 4, sd_multiplier = 1, exclude_buffer = FALSE, and tolerance = 0. Note: y-axis ranges differ to allow for effective comparison between road categories.

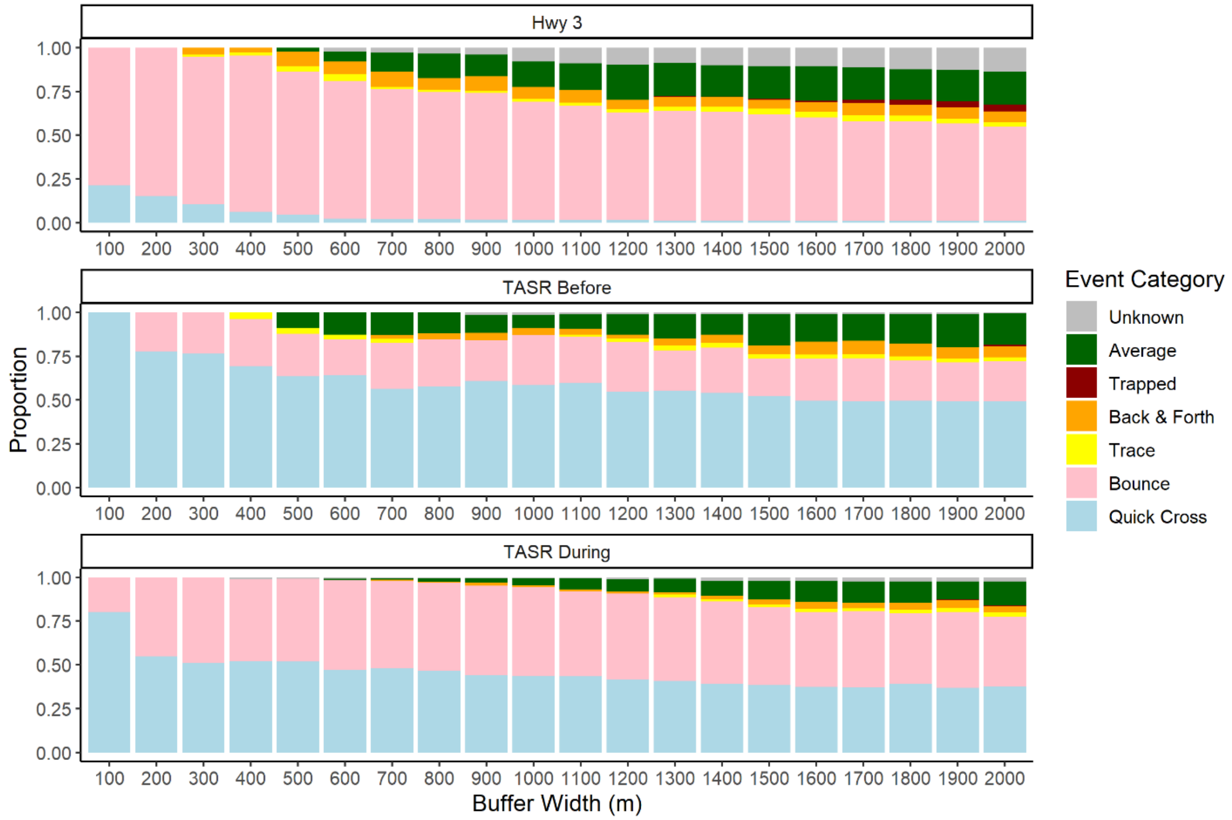

Figure S-2. Barplots of the frequency of the proportion of behaviour types for a range of buffer distances (100 to 2,000 m, by 100 m intervals) and the different highway categories of interest (Highway 3, Tłı̨chǫ ASR before construction, and Tłı̨chǫ ASR during construction), using the starting parameters: p_time = 36 hours, b_time = 4 hours, w = 7 days, max_cross = 4, sd_multiplier = 1, exclude_buffer = FALSE, and tolerance = 0.

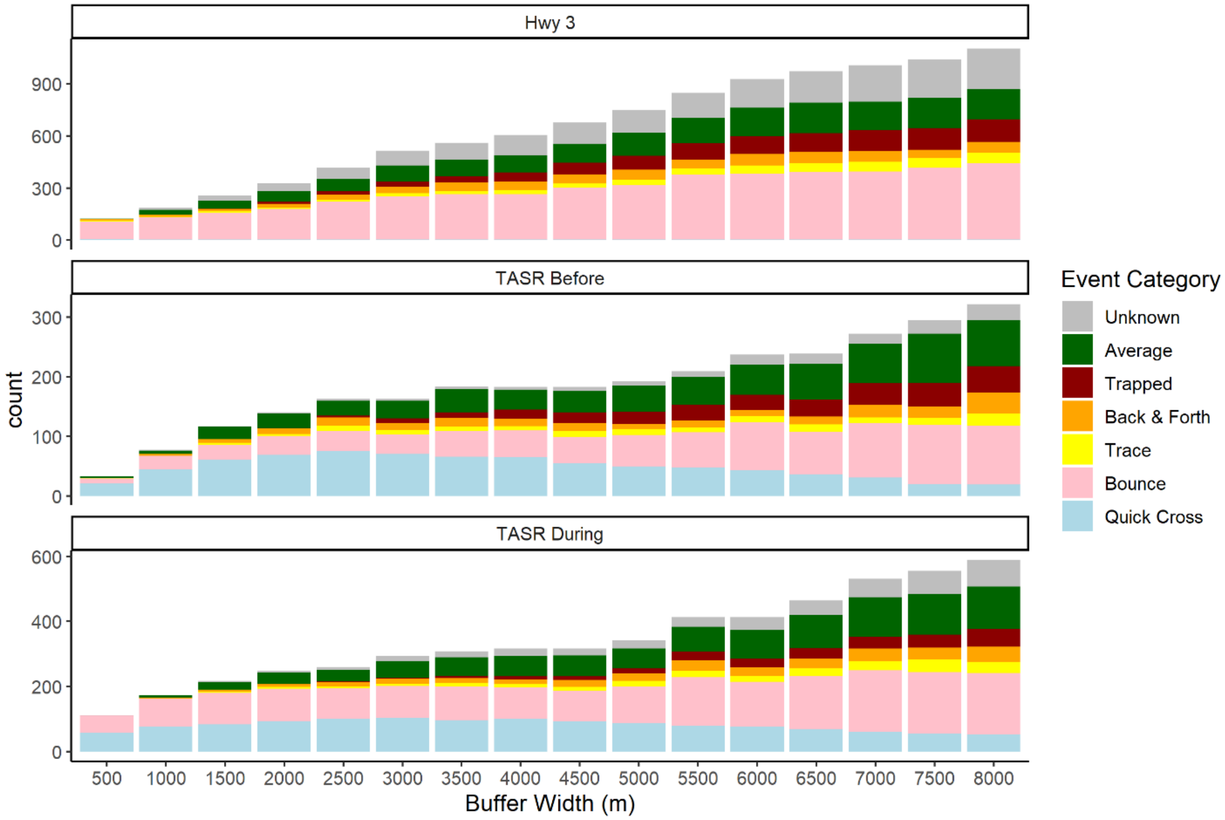

Figure S-3. Barplots of the frequency of various behaviour types for a range of buffer distances (500 to 8,000 m, by 500 m intervals) and the different highway categories of interest (Highway 3, Tłı̨chǫ ASR before construction, and Tłı̨chǫ ASR during construction), using the starting parameters: p_time = 36 hours, b_time = 4 hours, w = 7 days, max_cross = 4, sd_multiplier = 1, exclude_buffer = FALSE, and tolerance = 0. Note: y-axis ranges differ to allow for effective comparison between road categories.

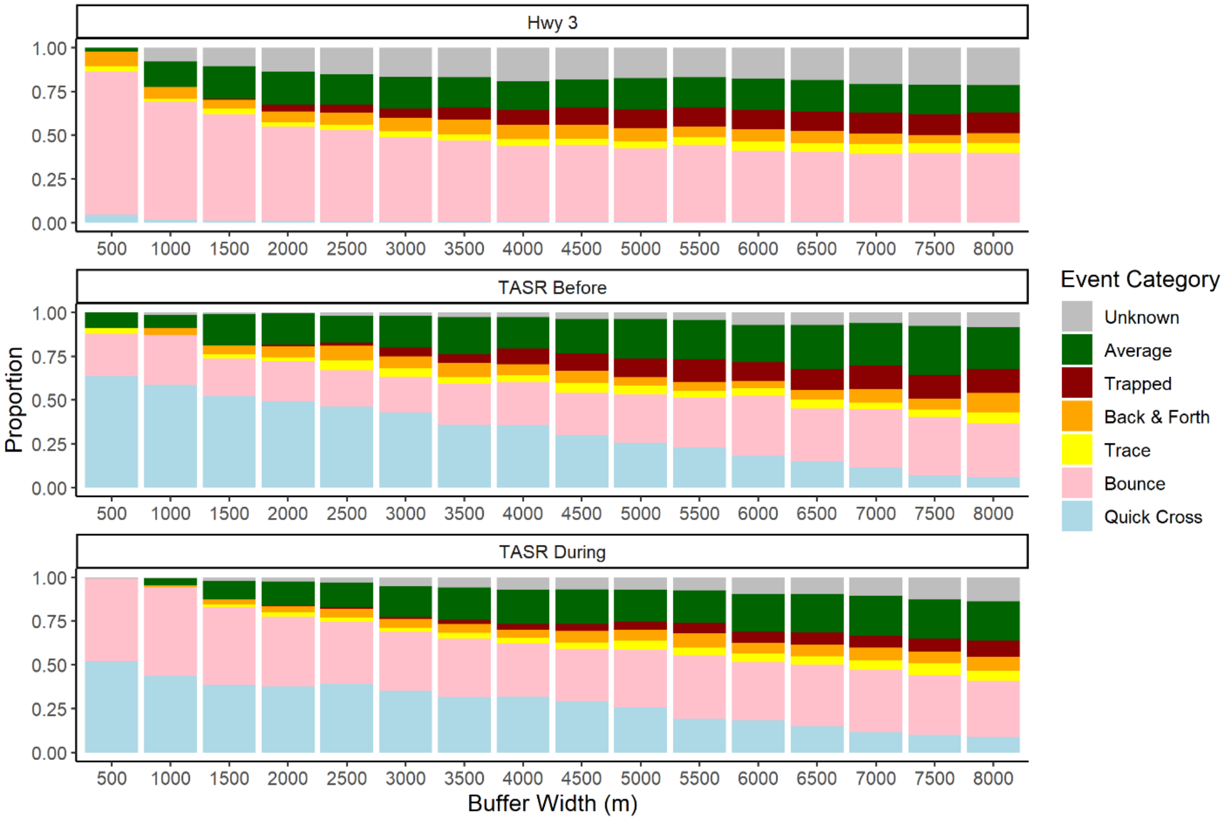

Figure S-4. Barplots of the proportion of various behaviour types for a range of buffer distances (500 to 8,000 m, by 500 m intervals) and the different highway categories of interest (Highway 3, Tłı̨chǫ ASR before construction, and Tłı̨chǫ ASR during construction), using the starting parameters: p_time = 36 hours, b_time = 4 hours, w = 7 days, max_cross = 4, sd_multiplier = 1, exclude_buffer = FALSE, and tolerance = 0.

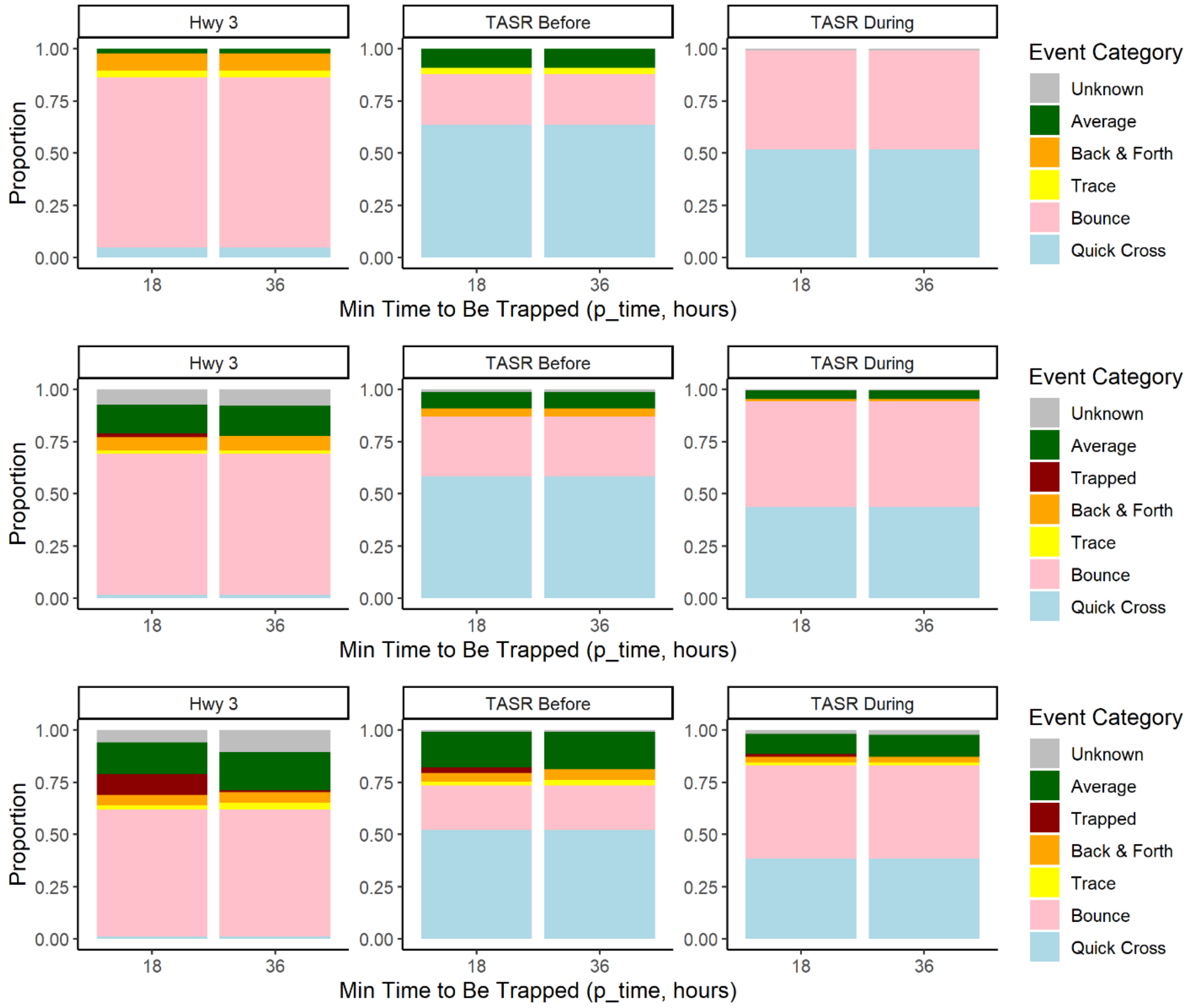

Figure S-5. Barplots of the proportion of behaviour types for different values of the "p_time" parameter for the various highway categories of interest (Highway 3, Tłı̨chǫ ASR before construction, and Tłı̨chǫ ASR during construction) and for a: a) 500 m buffer b) 1,000 m buffer and c) 1,500 m buffer. For the "p_time" parameter, which is the minimum time duration for an encounter event to be considered a "trapped" behaviour, values of 18 and 36 hours were tested for three chosen buffer distances (500, 1,000, and 1,500 m). Results showed that a bigger p_time value resulted in no to less trapped behaviours being detected for the 1,000- and 1,500-meter buffers, especially for Highway 3 (~9% increase in trapped behaviours for p_time of 18 hours for Highway 3 at the 1,500 m buffer). A larger proportion of "trapped" behaviours were detected at a p_time of 18 hours, which was likely an artifact of the smaller buffer size and not true "trapped" behaviour; therefore, we decided to use a p_time of 36 hours.

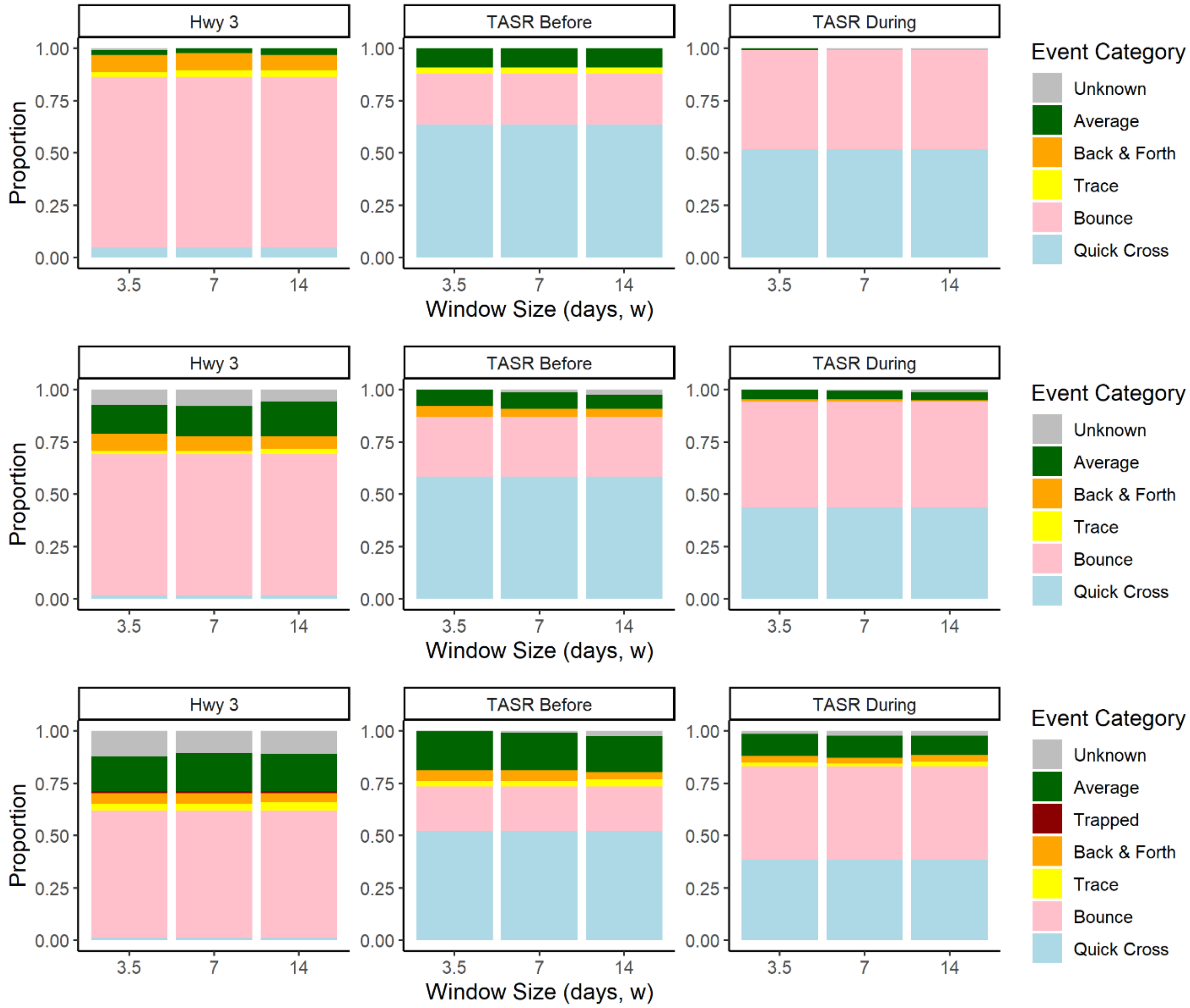

Figure S-6. Barplots of the proportion of behaviour types for different values of the “w” parameter for the various highway categories of interest (Highway 3, Tłįchǫ ASR before construction, and Tłįchǫ ASR during construction) and for a: a) 500 m buffer b) 1,000 m buffer and c) 1,500 m buffer. For the “w” parameter, which is the moving window size used in calculating average straightness of movement, for the 1,000 m buffer, a larger window size of 14 days corresponded to a ~2% increase in average behaviours detected for Highway 3 but a 2% decrease in average behaviours for Highway 9 before construction. A similar pattern was seen for the 1,500 m buffer. These small changes indicated that the BaBA was not sensitive to differences in the w parameter and a w of 7 days was used (similar to Xu et al. (2021)).

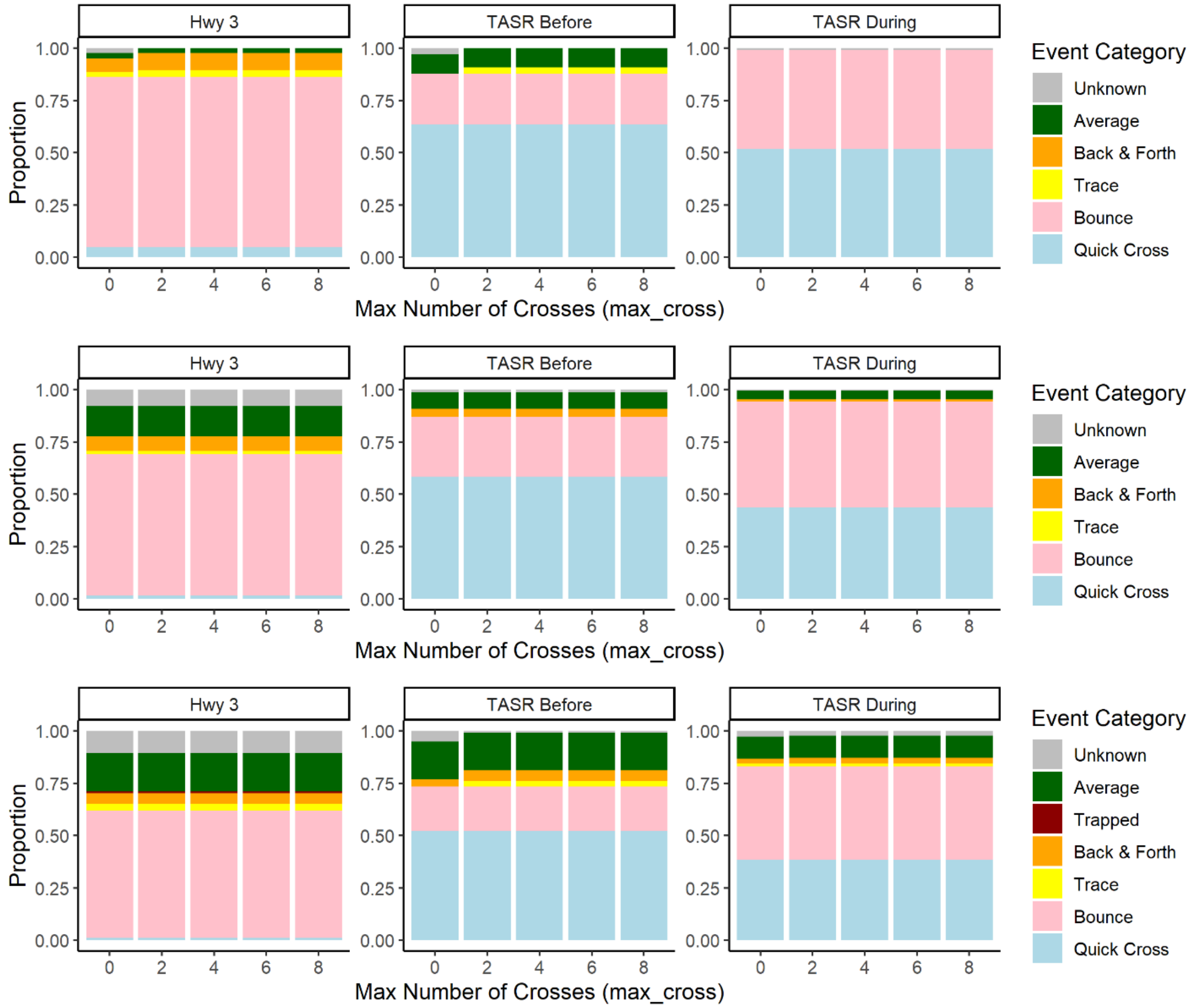

Figure S-7. Barplots of the proportion of behaviour types for different values of the “max_cross” parameter for the various highway categories of interest (Highway 3, Tłı̨chǫ ASR before construction, and Tłı̨chǫ ASR during construction) and for a: a) 500 m buffer b) 1,000 m buffer and c) 1,500 m buffer. For the “max_cross” parameter, which is the maximum number of crosses to be allowed for detecting trace and back-and-forth behaviours, values of 0, 2, 4, 6, and 8 days were compared between the different road categories. This parameter accommodates data resolution issues so that, e.g., if the road curves and the straight line connecting subsequent caribou locations intersects the curve even if the caribou has most likely remained on a single side of the road, those “crosses” are not considered. For the 500 m buffer, there was more back-and-forth behaviour for max_cross values of 2 and 4 for Highway 3 (~2% difference) and no trace behaviour detected at a max_cross of 0 (classified as "unknown" instead). For the 1,500 m buffer, for the Tłı̨chǫ ASR before construction, the presence of unknown behaviours (~5%) for a max_cross of 0 corresponded to a total loss of trace behaviours and ~2% of back-and-forth behaviours. However, these small differences largely supported that BaBA was not sensitive to the max_cross parameter and a max_cross of 2 was chosen.

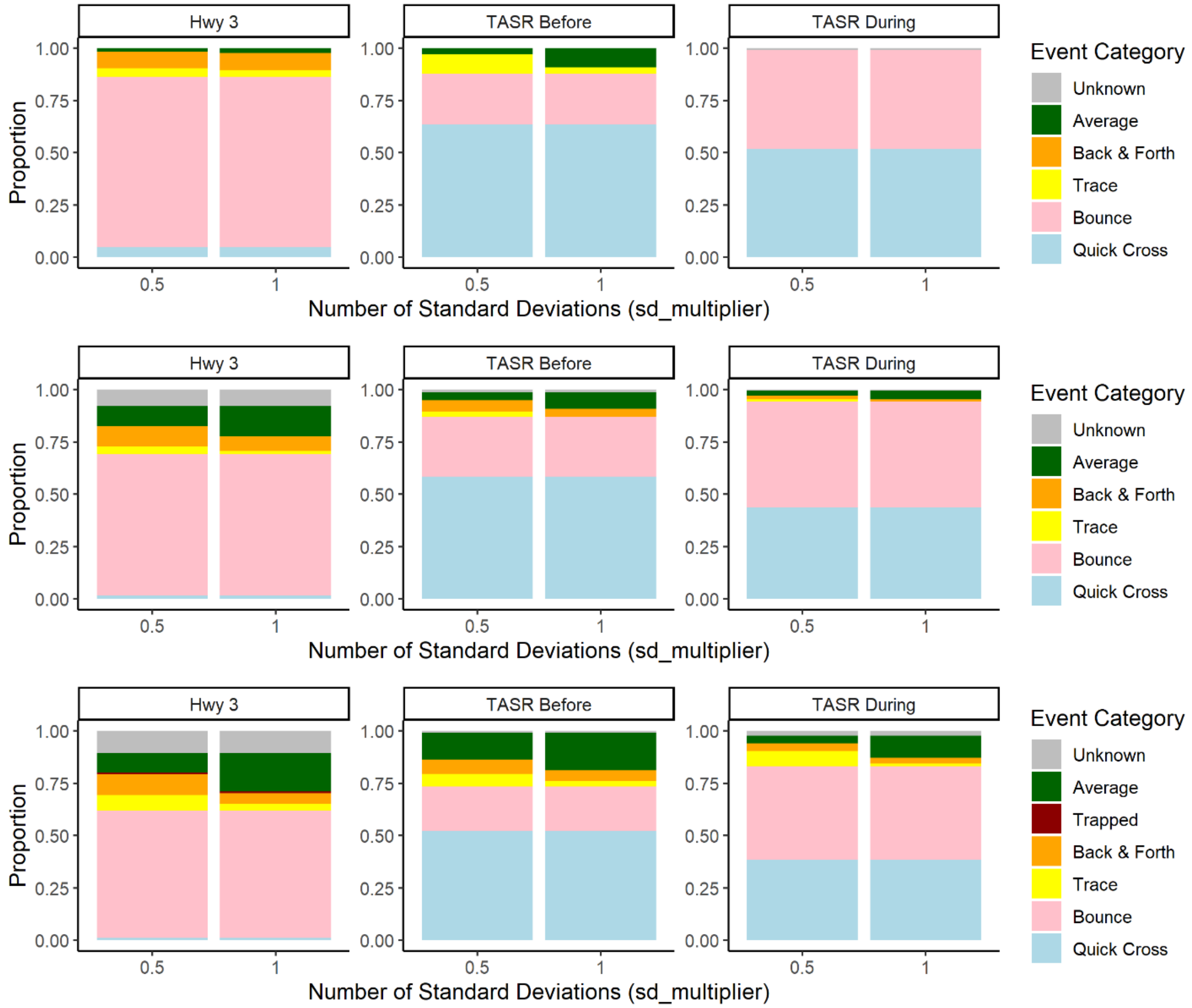

Figure S-8. Barplots of the proportion of behaviour types for different values of the "sd_multiplier" parameter for the various highway categories of interest (Highway 3, Tłı̨chǫ ASR before construction, and Tłı̨chǫ ASR during construction) and for a: a) 500 m buffer b) 1,000 m buffer and c) 1,500 m buffer. For the "sd_multiplier" parameter, which is the number of standard deviations that define "normal" straightness values for movement, for the 500 m buffer, for the Tłı̨chǫ ASR before construction, there was an ~6% increase in average behaviour and ~6% corresponding decrease in trace behaviour for an SD of 1 versus an SD of 0.5. For the 1,000 m buffer, for Highway 3 there was a ~4% increase in average movement for an SD of 1 compared to an SD of 0.5 (and corresponding decrease in back-and-forth and trace behaviours); for the Tłı̨chǫ ASR before construction, an increase in average behaviours for an SD of 1 (~4%) corresponded to an absence of trace behaviours for an SD of 1 and a similar trend was seen for the Tłı̨chǫ ASR during construction (~2% increase in average behaviours for an SD of 1). For the 1,500 m buffer, similar trends were seen, with Highway 3 having an increase in the proportion of average behaviours with an SD of 1 (~9%) corresponding to a decrease in back-and-forth and trace behaviours; the Tłı̨chǫ ASR before construction had an increase in the proportion of average behaviours with an SD of 1 (~5%) corresponding to a decrease in back-and-forth and trace behaviours; and the Tłı̨chǫ ASR during construction had an increase in the proportion of average behaviours with an SD of 1 (~7%) corresponding to a decrease in back-and-forth and trace behaviours. An SD of 0.5 was chosen to use going forward, as it allowed for more "back-and-forth" and "trace" behaviours to be identified.

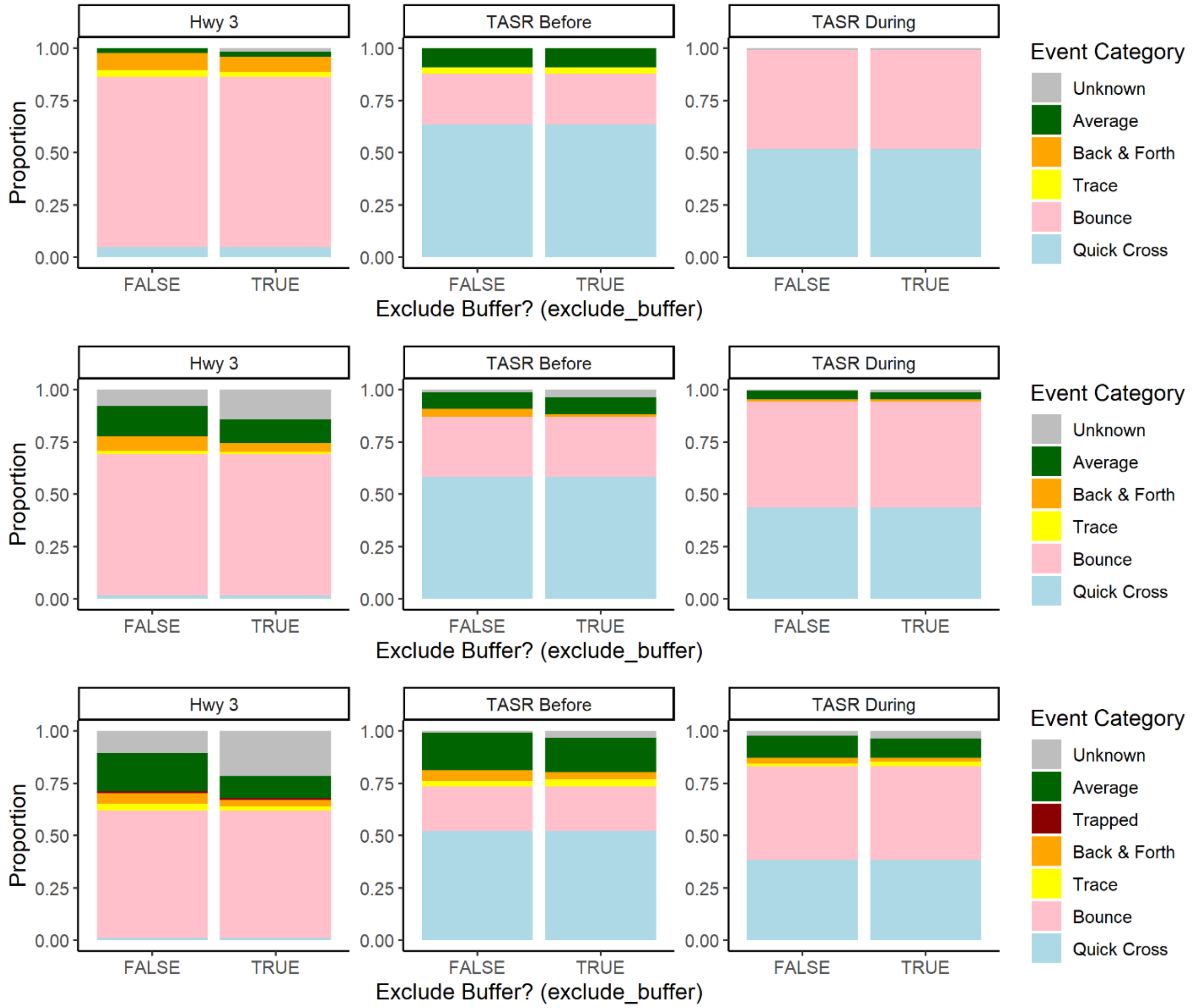

Figure S-9. Barplots of the proportion of behaviour types for different values of the “exclude_buffer” parameter for the various highway categories of interest (Highway 3, Tłı̨chǫ ASR before construction, and Tłı̨chǫ ASR during construction) and for a: a) 500 m buffer b) 1,000 m buffer and c) 1,500 m buffer. For the “exclude_buffer” parameter, which specifies whether to include locations within the barrier buffer when determining the average straightness of movement and can be useful for controlling barrier effects, for the 500 m buffer, small differences in proportions were seen for Highway 3 and when exclude_buffer was “TRUE”, with an increase in "unknown" behaviours (~2%) corresponding with a decrease in trace and back-and-forth behaviours. For the 1,000 m buffer, a similar pattern was seen for Highway 3, with a decrease in average, back-and-forth, and trace behaviours for when exclude_buffer was “TRUE”; for the Tłı̨chǫ ASR before construction, an increase in unknown behaviours (~6%) corresponded to a decrease in back-and-forth behaviour. For the 1,500 m buffer, this trend was seen again in stronger magnitude, with for Highway 3, an increase in unknown behaviours (~11%) when the exclude_buffer was “TRUE”; and for the Tłı̨chǫ ASR before construction, a ~2% decrease in average behaviour corresponded to a ~2% increase in unknown behaviour when the exclude_buffer was “TRUE”. Given the larger number of “unknowns” with the exclude_buffer of “TRUE” and that Xu et al. (2021) used an exclude_buffer of “FALSE”, we chose to use an exclude_buffer of “FALSE”.

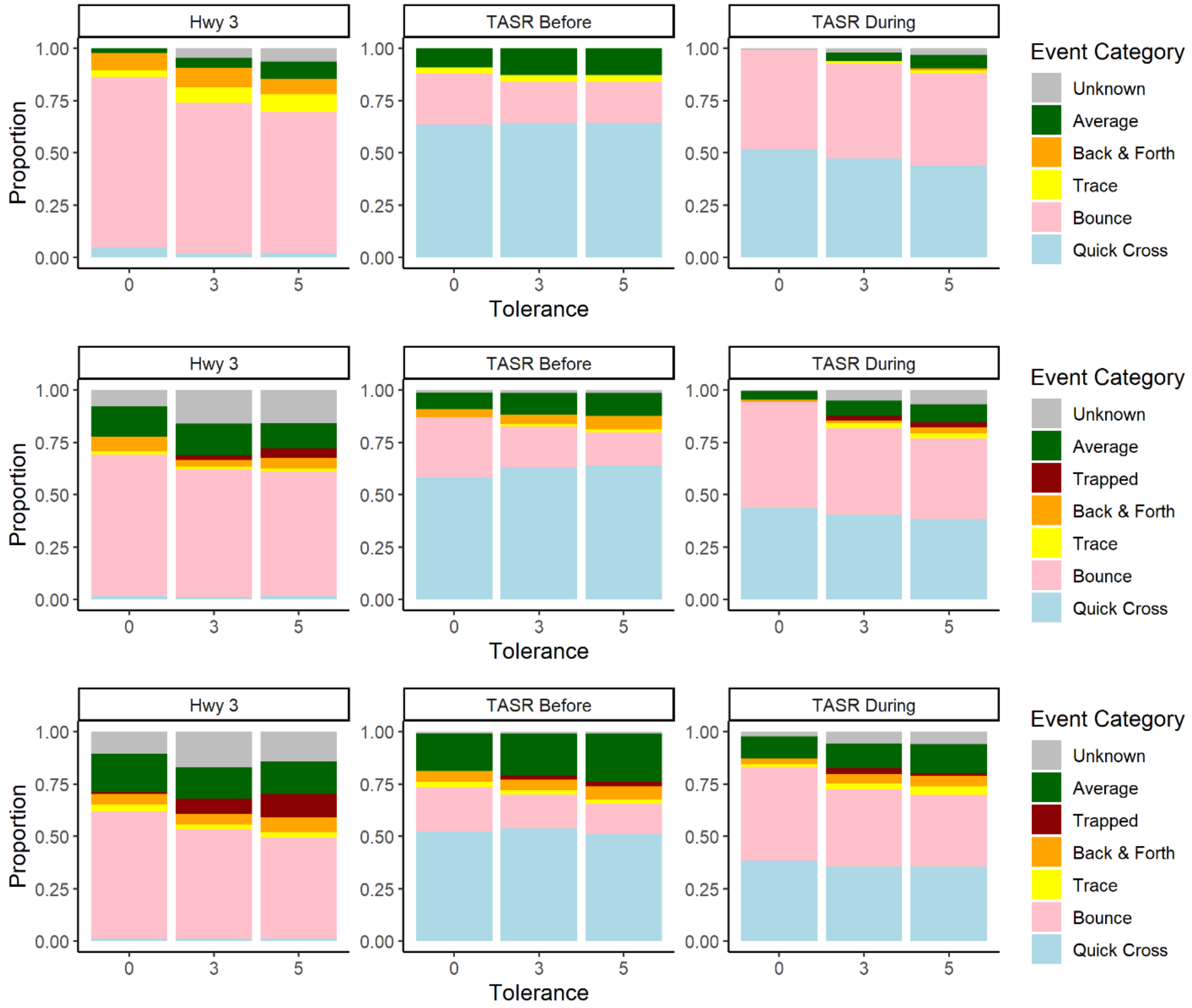

Figure S-10. Barplots of the proportion of behaviour types for different values of the "tolerance" parameter for the various highway categories of interest (Highway 3, Tłı̨chǫ ASR before construction, and Tłı̨chǫ ASR during construction) and for a: a) 500 m buffer b) 1,000 m buffer and c) 1,500 m buffer. For the "tolerance" parameter, which defines the maximum duration to allow points outside of the buffer and between 2 sets of points that are inside the buffer to be considered a continuous encounter event, values of 0, 3, and 5 hours were tested. For the 500 m buffer and Highway 3, a higher tolerance parameter resulted in a higher (~4%) proportion of trace behaviour and for the Tłı̨chǫ ASR during construction, a higher tolerance parameter of 3-5 hours resulted in the emergence of other behaviours (~1% trace, ~4-6% average, ~2-3% unknown). For the 1,000 m buffer and Highway 3, an increase in the tolerance parameter correlated with an increase (~2-3%) in trapped behaviour; for the Tłı̨chǫ ASR before construction, trace behaviour (1-2%) emerged with a tolerance of 3-5 hours, whereas for the Tłı̨chǫ ASR during construction, both trace and trapped behaviour (~ 2% each) emerged with a tolerance of 3-4 hours. For the 1,500 m buffer and Highway 3, an increase (~3-6%) in the proportion of trapped behaviour occurred with higher tolerance behaviour (and a ~1% decrease in trace behaviour). A tolerance of three hours was decided to be used going forward, as having a few locations leave the buffer during an encounter is logical.

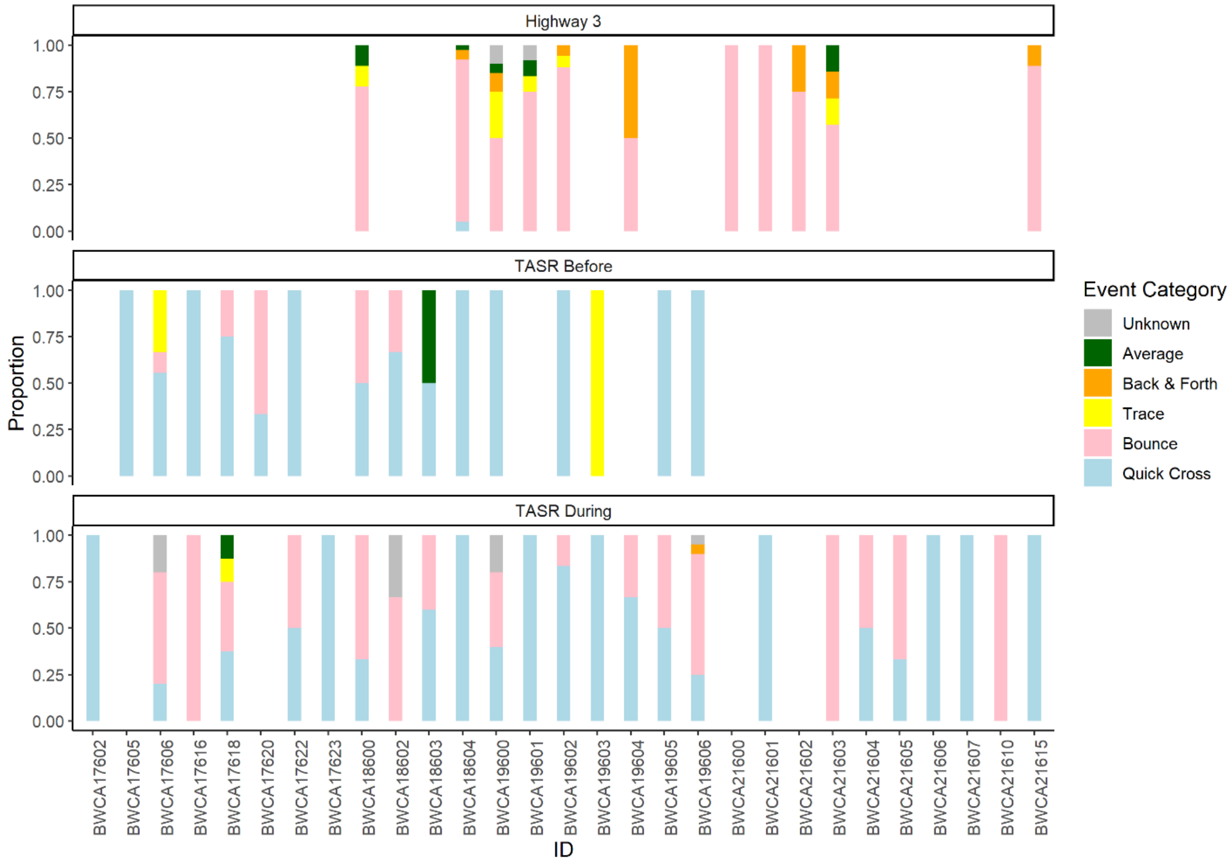

Figure S-11. Barplots of the proportion of various behaviour types for a buffer distance of 500 m and comparing the different highway categories of interest (Highway 3, Tłı̨chǫ ASR before construction, and Tłı̨chǫ ASR during construction) for different individuals.

Figure S-12. Barplots of the frequency of various behaviour types for a buffer distance of 500 m and comparing the different highway categories of interest (Highway 3, Tłı̨chǫ ASR before construction, and Tłı̨chǫ ASR during construction) for different individuals. Note: y-axis ranges differ to allow for effective comparison between road categories.

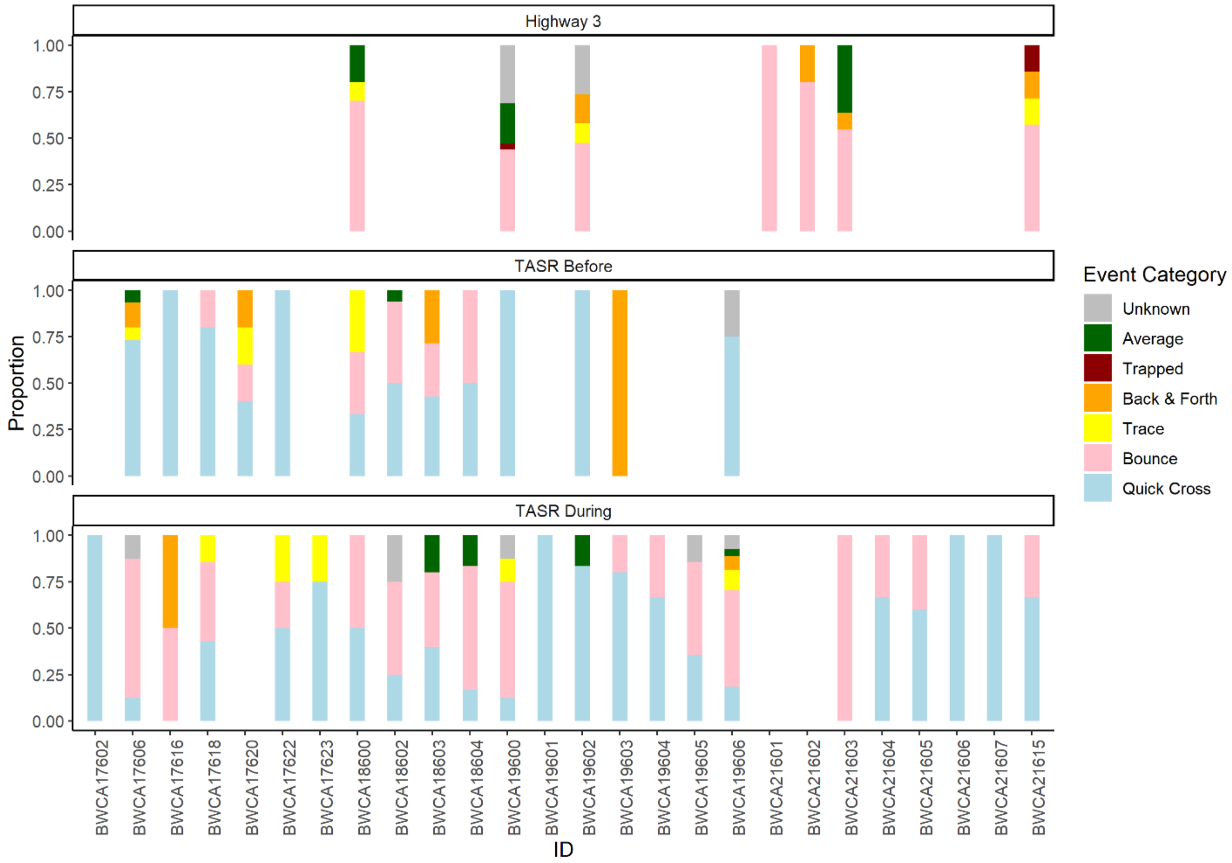

Figure S-13. Barplots of the proportion of various behaviour types for a buffer distance of 1,000 m and comparing the different highway categories of interest (Highway 3, Tłı̨chǫ ASR before construction, and Tłı̨chǫ ASR during construction) for different individuals.

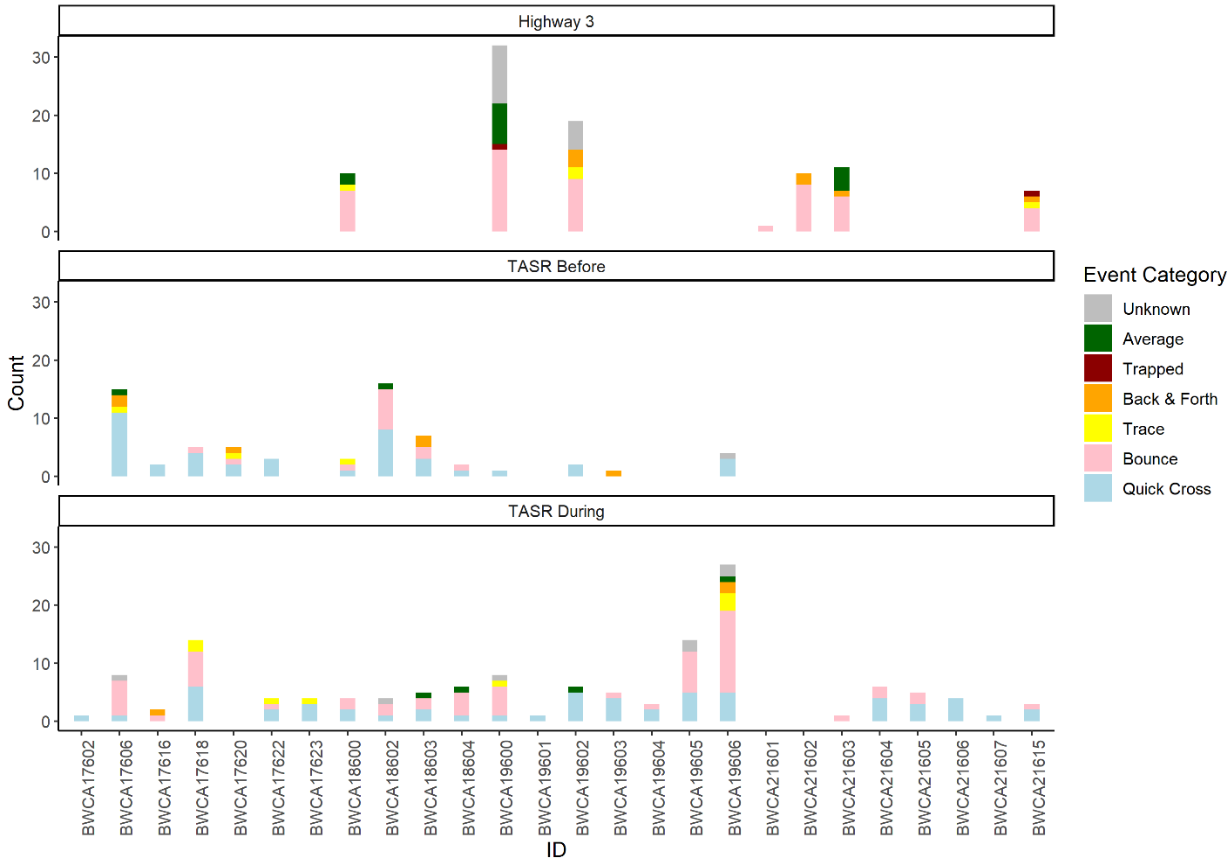

Figure S-14. Barplots of the frequency of various behaviour types for a buffer distance of 1,000 m and comparing the different highway categories of interest (Highway 3, Tłı̨chǫ ASR before construction, and Tłı̨chǫ ASR during construction) for different individuals. Note: y-axis ranges differ to allow for effective comparison between road categories.